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STRESS DISTRIBUTIONS AROUND PIPE CROSS SECTIONS

by

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[redacted]

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ABSTRACT

This thesis presents a method for estimating the distribution of stress components around the outer circumference of a cross section of a pipe, from the readings of strain gage elements arbitrarily positioned and oriented around this circumference. A least-squares procedure is used to obtain best estimates of the coefficients of Fourier expansions describing such distributions. A digital computer program was developed for applying the method. Data for testing the method and program were generated by a computer program using the best available theory of stress analysis in pipes. Methods for adding random errors to the data were adapted and used for closer simulation of actual situations.

A second problem treated in this thesis is that of inferring the loading acting through the cross section of a straight pipe of concentric bore from known stresses at points on the external surface of the cross section which is presumed to be distant from stress concentrations. It is shown that this inference can be made from stresses at only three points of the cross section. A digital computer program was developed to do this.

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1. Introduction.

In a thesis presented to the Naval Postgraduate School in May, 1966, LT Joseph W. Koch, Jr., USN, did pioneer work on the problem of obtaining optimal inferences of stresses in submarine main sea water piping, from strain gage readings taken during dockside hydrostatic tests and during submerged operations. This work provided a sequential procedure for determining such stresses, but it also indicated the need for many related investigations.

Two of these are treated in the present thesis. The first is that of inferring, in an optimal way, the distributions of stresses around the outer circumference of a given cross section of pipe from observations of strain obtained from an arbitrary distribution of strain gage elements around that circumference. There are several reasons for being interested in this problem. One reason is that even though the gage elements may be arranged in special patterns intended to simplify determining stresses (for example three-gage rosette arrangements), failure of any of the elements might make it difficult to make effective use of valid information obtained from closely related gages. Another reason is the ability to infer stresses from arbitrarily arranged gages, which is a logical step in investigating the most effective and most economical arrangements of gage elements.

Briefly, this problem is solved herein by constructing Fourier series representing the desired stress components. Theoretical considerations are used to evaluate the coefficients of the series in an optimal way, minimizing the sum of the squares of the residuals. A digital computer program was developed to support the theory.

The second problem treated here is that of inferring the force and moment components applied through a cross section of pipe and the internal pressure acting inside the pipe. It is shown that these values may be inferred from a knowledge of the state of stress at only three abritrarily chosen points at the external circumference of the cross section, and a digital computer program for making the corresponding evaluations was developed.

The solution of this problem assumes that the stress distribution is that given by what may be regarded as the best available current theory for the state of stress in a section of uniform pipe having concentric bore and remote from stress concentrations and other disturbances in the stress pattern.

A digital computer program to generate numerical data from the best available theory was developed. This data was used to test and verify the theory and the computer programs. Suggestions of how to extend the present work are given in Section 4.

The author would like to express his sincere appreciation to Dr. John E. Brock, Professor of Mechanical Engineering, Naval Postgraduate School, for his continued patience, efforts and most capable guidance while acting as faculty advisor in this work.

2. Least-Squares Estimation of Stress Distributions at the External Circumference of a Pipe by Means of Fourier Expansions, Using Strain Gage Data.

The usual method of estimating the stress distribution at the surface of a body is by taking readings of strain gages grouped in rosettes, to determine local principal stresses. Unless the strain rosettes have a redundance of gage elements, when one or more of them fail, it is difficult to make effective use of the information provided by the elements which do not fail.

The work that follows presents a method to estimate the stress distribution around an external circumference of a cross section of pipe, along a sequence of strain gage elements, which may or may not be grouped in rosettes. If one or more gage elements fail, the information from the others is still useful.

It is assumed that strain gage elements are arbitrarily placed

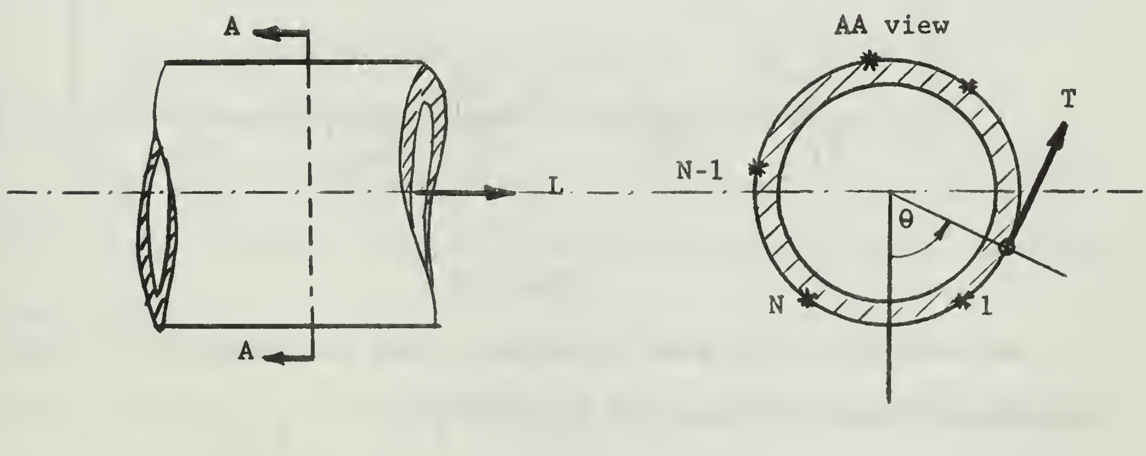

Fig. 2.1.

and arbitrarily oriented around the external circumference of a cross section of pipe so as to measure the strain produced by application of

loading. Assume that there are N such elements as indicated in Fig. 2.1.

Define two orthogonal directions at the cross section, one normal to it, called longitudinal and represented by the letter L, and the other tangential to the external circumference, called tangential and represented by T; Fig. 2.1.b. Also define the angle θ as the angle between the vertical line that passes downward through the center of the cross section, and the radial line that passes through any specified point of the external circumference, measured as indicated in Fig. 2.1.b.

Measure the angular orientation of each gage element in the counterclockwise direction from the tangential axis T, and call this angle $\emptyset$.

A set of parameter-pairs can then be formed

$$(\theta_i \; , \; \emptyset_i) \qquad i = 1, 2, \ldots , N$$

which describe the position and orientation of each element, Fig. 2.2.

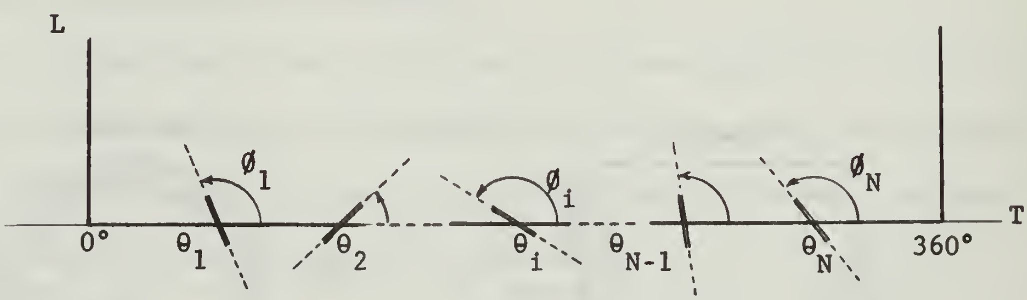

Fig. 2.2.

At each one of the gage locations, there are tangential, longitudinal, and shear strains, $(\epsilon_T)_i$, $(\epsilon_L)_i$, and $(\epsilon_{TL})_i$ respectively. The strains ϵ_y and ϵ_z along axis y and z, rotated the angle $\emptyset$ from the tangential direction Fig. 2.3., are related to the local

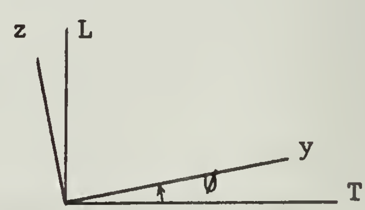

Fig. 2.3.

strains ϵ_T, ϵ_L and ϵ_{TL} by the strain tensor in the following way

$$\begin{bmatrix} \epsilon_y & \frac{1}{2}\epsilon_{yz} \\ \frac{1}{2}\epsilon_{yz} & \epsilon_z \end{bmatrix} = \begin{bmatrix} \cos \phi & \sin \phi \\ -\sin \phi & \cos \phi \end{bmatrix} \begin{bmatrix} \epsilon_T & \frac{1}{2}\epsilon_{TL} \\ \frac{1}{2}\epsilon_{TL} & \epsilon_L \end{bmatrix} \begin{bmatrix} \cos \phi & -\sin \phi \\ \sin \phi & \cos \phi \end{bmatrix}$$

The corresponding relations for the strains $(\epsilon_y)_i$ and $(\epsilon_z)_i$ along and transverse to the ith strain gage axis, are then

$$(\epsilon_y)_i = (\epsilon_T)_i \sin^2\phi_i + (\epsilon_L)_i \cos^2\phi_i + (\epsilon_{TL})_i \sin \phi_i \cos \phi_i \qquad (2.1.1)$$

$$(\epsilon_z)_i = (\epsilon_T)_i \cos^2\phi_i + (\epsilon_L)_i \sin^2\phi - (\epsilon_{TL})_i \sin\phi_i \cos \phi_i \qquad (2.1.2)$$

At the external surface, strains are related to the corresponding stresses as follows

$$\epsilon_T = (s_T - v\, s_L)\,/E \qquad (2.2.1)$$

$$\epsilon_L = (s_L - v\, s_T)\,/E \qquad (2.2.2)$$

$$\epsilon_{T_L} = s_{TL}\,/\,G \qquad (2.2.3)$$

where s is stress

v is Poisson's ratio

E is Young's modulus of elasticity

G is the shear modulus of elasticity

Substituting these expressions for the strains in the relations (2.1) for the strains along and transverse to the ith gage element and simplifying

$$(\epsilon_y)_i = (s_T)_i[1 - (v + 1)\sin^2\phi_i]/E + (s_L)_i[1 - (v + 1)\cos^2\phi_i]/E$$
$$+(s_{TL})_i \sin 2\,\phi_i/(2G) \qquad (2.3.1)$$

$$(\epsilon_z)_i = (s_T)[1 - (v + 1)\cos^2\phi_i]/E + (s_L)_i[1 - (v + 1)\sin^2\phi_i]/E$$

$$- (s_{TL})_i \sin 2\,\phi_i/(2G) \qquad (2.3.2)$$

A strain gage element is sensitive not only to the strain along its own axis but also, to a small extent, to the strain at right angles to this axis. The transverse sensitivity is usually hard to obtain. It is rarely available from the manufacturer and may have to be inferred from an experiment. Nevertheless, it may be of importance and it is included in the theoretical development that follows.

For a particular gage element properly mounted on a given definite material, the relative change in electrical resistance, which is sensed by the strain indicator (or recorder), is given by a formula of the sort

$$\frac{\Delta R}{R} = F_y\,\epsilon_y + F_z\,\epsilon_z \qquad (2.4)$$

where R is the electrical resistance of the element, ϵ_y and ϵ_z are the strains along and perpendicular to its axis, and F_y and F_z are coefficients which depend on the characteristics of the gage and the properties of the material upon which it is mounted.

The ratio

$$k = F_z\,/\,F_y \qquad (2.5)$$

is called the transverse sensitivity (factor) of the gage, and the quantity

$$F' = (1 - k^2)\,F_y$$

is called the gage factor (which should be set on the sensor instrument). F' is the ratio of unit change in electric resistance to the quantity e, (indicated strain) sensed by the instrumentation.

Thus $$e = \left(\frac{\Delta R}{R} \right) / F'$$

$$= (F_y \epsilon_y + F_z \epsilon_z)/[(1 - k^2)F_y]$$

$$= (\epsilon_y + k\epsilon_z)/(1 - k^2) \qquad (2.7)$$

This is what the instrumentation should indicate if there were no errors. Clearly for a gage with no transverse sensitivity, k = 0, and $e = \epsilon_y$.

After substituting the expressions (2.3) for $(\epsilon_y)_i$ and $(\epsilon_z)_i$ in equation (2.7) and simplifying, the theoretical indicated strain e_i sensed along the ith strain gage element is given by

$$e_i = (s_T)_i[(1 - kv) - (1 - k)(1 + v)\sin^2\emptyset_i]/[E(1 - k^2)] +$$

$$+ (s_L)_i[(1 - kv) - (1 - k)(1 + v)\cos^2\emptyset_i]/[E(1 - k^2)2 +$$

$$+ (s_{TL})_i(1 - k)\sin 2\emptyset_i/[2G(1 - k^2)] \qquad (2.8)$$

Let the coefficients of the stresses in the above expression be represented by

$$A(\emptyset_i) = A_i = [(1 - kv) - (1 - k)(1 +v)\sin^2\emptyset_i]/[E(1 - k^2)] \qquad (2.9.1)$$

$$B(\emptyset_i) = B_i = [(1 - kv) - (1 - k)(1 + v)\cos^2\emptyset_i]/[E(1 - k^2)] \qquad (2.9.2)$$

$$C(\emptyset_i) = C_i = (1 - k)\sin 2\emptyset_i/[2G(1 - k^2)] \qquad (2.9.3)$$

Then equation (2.8) can be put in the form

$$e_i = A_i(s_T)_i + B_i(s_L)_i + C_i(s_{TL})_i \qquad (2.10)$$

Any one of the stresses $(s_T)_i$, $(s_L)_i$ and (s_{TL}) has continuous and finite values around the external circumference of the pipe cross

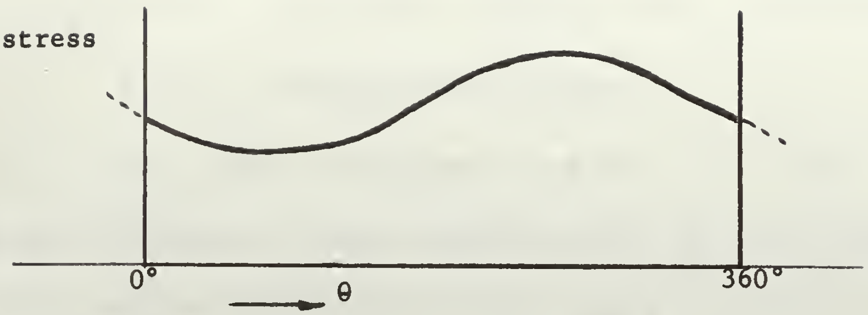

Fig. 2.4.

section, and can be represented as in Fig. 2.4.

The functional relation between stress and the angular position θ can be expanded in an infinite Fourier series[1]

$$(s_T)_i = \sum_{n=0}^{\infty} (s_{TA})_n \cos n\theta_i + \sum_{n=0}^{\infty} (s_{TB})_n \sin n\theta_i \qquad (2.11.1)$$

$$(s_L)_i = \sum_{n=0}^{\infty} (s_{LA})_n \cos n\theta_i + \sum_{n=0}^{\infty} (s_{LB})_n \sin n\theta_i \qquad (2.11.2)$$

$$(s_{TL})_i = \sum_{n=0}^{\infty} (s_{TLA})_n \cos n\theta_i + \sum_{n=0}^{\infty} (s_{TLB})_n \sin n\theta_i \qquad (2.11.3)$$

where

$(s_{TA})_n$, $(s_{TB})_n$, $(s_{LA})_n$, $(s_{LB})_n$, $(s_{SHA})_n$, and $(s_{SHB})_n$ are as yet unknown numerical coefficients.

Sufficiently accurate values can be obtained if the expansion is carried to a finite number of terms, say P terms, in which case the index n would reach a maximum value of P/2. Call this value M. Then

$$(s_T)_i \approx \sum_{n=0}^{M} (s_{TA})_n \cos n\theta_i + \sum_{n=0}^{M} (s_{TB})_n \sin n\theta_i \qquad (2.12.1)$$

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[1] The conventional expansion of a Fourier series is a constant term followed by a summation from 1 to ∞ . The same is obtained by eliminating the constant term and making summations from 0 to ∞ . This latter form will be used in this work to facilitate mathematical manipulations and later programming for a digital computer.

$$(s_L)_i \approx \sum_{n=0}^{M} (s_{LA})_n \cos n\theta_i + \sum_{n=0}^{M} (s_{LB})_n \sin \theta_i \qquad (2.12.2)$$

$$(s_{TL})_i \approx \sum_{n=0}^{M} (s_{TLA})_n \cos n\theta_i + \sum_{n=0}^{M} (s_{TLB})_n \sin n\theta_i \qquad (2.12.3)$$

Note that this expansion contains 6(M + 1) Fourier coefficients. If these expressions for the stresses are substituted into equation (2.10) for the strain e_i, theoretically sensed by the ith strain gage element,

$$\begin{aligned} e_i \approx \; & A_i[\sum_{n=0}^{M} (s_{TA})_n \cos n\theta_i + \sum_{n=0}^{M} \ldots] + \\ & + B_i[\sum_{n=0}^{M} \ldots + \sum_{n=0}^{M} \ldots] + \\ & + C_i[\sum_{n=0}^{M} \ldots + \sum_{n=0}^{M} (s_{TLB})_n \sin n\theta_i] \end{aligned} \qquad (2.13)$$

Call e_i^* the strain actually measured by the ith strain gage element, and E_i the difference between that measured strain and e_i, the strain that theoretically it should have measured, so that this error E_i is expressed as

$$E_i = e_i - e_i^* \qquad (2.14)$$

Let R be the sum of the squares of the errors, that is

$$\begin{aligned} R &= \sum_{i=1}^{N} (E_i)^2 \\ &= \sum_{i=1}^{N} (e_i - e_i^*)^2 \\ &= \sum_{i=1}^{N} (e_i)^2 - 2 \sum_{i=1}^{N} e_i e_i^* + \sum_{i=1}^{N} (e_i^*)^2 \end{aligned} \qquad (2.15)$$

To minimize R, partial derivatives respect to each of the 6(M + 1) Fourier coefficients are taken and set equal to zero:

$$\frac{\partial R}{\partial D_k} = 0$$

where $D_k = (s_{TA})_k$, $(s_{TB})_k$, $(s_{LA})_k$, $(s_{LB})_k$, $(s_{TLA})_k$, $(s_{TLB})_k$ in turn

for k = 0, 1, 2, ..., M

Taking derivatives of R from expression (2.15)

$$\frac{\partial R}{\partial D_k} = 0 = 2 \sum_{i=1}^{N} e_i \frac{\partial e_i}{\partial D_k} - 2 \sum_{i=1}^{N} e_i^* \frac{\partial e_i}{\partial D_k} \qquad (2.16)$$

Simplifying this

$$\sum_{i=1}^{N} e_i \frac{\partial e_i}{\partial D_k} = \sum_{i=1}^{N} e_i^* \frac{\partial e_i}{\partial E_k} \qquad (2.17)$$

Taking derivatives of e_i from expression (2.13)

$$\frac{\partial e_i}{\partial (s_{TA})_k} = A_i \cos k\theta_i \quad \text{for } k = 0, 1, 2, \ldots, M \qquad (2.18.1)$$

$$\frac{\partial e_i}{\partial (s_{TB})_k} = A_i \sin k\theta_i \qquad (2.18.2)$$

$$\frac{\partial e_i}{\partial (s_{LA})_k} = B_i \cos k\theta_i \qquad (2.18.3)$$

$$\frac{\partial e_i}{\partial (s_{LB})_k} = B_i \sin k\theta_i \qquad (2.18.4)$$

$$\frac{\partial e_i}{\partial (s_{TLA})_k} = C_i \cos k\theta_i \qquad (2.18.5)$$

$$\frac{\partial e_i}{\partial (s_{TLB})_k} = C_i \sin k\theta_i \qquad (2.18.6)$$

Note that there are 6(M + 1) derivatives of this form. Substituting in equation (2.17) the expression for e_i from equation (2.13)

$$\sum_{i=1}^{N} \left\{ A_i \left[\sum_{n=0}^{M} (s_{TLB})_n \sin n\theta_i + \ldots \right] + \ldots + C_i \left[\ldots \right. \right.$$
$$\left. \left. \ldots + \sum_{n=0}^{M} (s_{TLB})_n \sin n\theta_i \right] \right\} \frac{\partial e_i}{\partial D_k} = \sum_{i=1}^{N} e_i^* \frac{\partial e_i}{\partial D_k}$$

(2.19)

which is the same as

$$\sum_{n=0}^{M} (s_{TA})_n \left[\sum_{i=1}^{N} A_i \cos n\theta_i \frac{\partial e_i}{\partial D_K}\right] + \sum_{n=0}^{N} (s_{TB})_n \left[\sum_{i=1}^{N} A_i \sin n\theta_i \frac{\partial e_i}{\partial D_K}\right] +$$

$$+ \cdots + \sum_{n=0}^{M} (s_{TLB})_n \left[\sum_{i=1}^{N} C_i \sin n\theta_i \frac{\partial e_i}{\partial D_K}\right] = \sum_{i=1}^{N} e_i^* \frac{\partial e_i}{\partial D_K} \qquad (2.20)$$

for k = 0, 1, 2, ... , M

When the index n in the Fourier expansions is equal to zero, the terms containing $\sin(n\theta_i)$ are zero. This makes the coefficients $(s_{TB})_0$, $(s_{LB})_0$ and $(s_{TLB})_0$ also zero, reducing the Fourier coefficients to (6M + 3) and the same number of derivatives of the form $\frac{\partial e_i}{\partial D_k}$. There will be (6M + 3) equations in each of which appear all the Fourier coefficients. This makes a set of (6M + 3) equations with the same number of unknowns, (the Fourier coefficients), which can be solved.

Once the Fourier coefficients are solved for, they can be substituted in expressions (2.7) for the stresses. The stress distributions s_T, s_L and s_{TL} are defined then as functions of the angle θ over the complete external circumference of the cross section.

A digital computer program was developed to apply the theory of the preceding text. It was tested using a mathematical model of a cantilevered pipe. The program is called TERESITA and is presented in Appendix B of this thesis.

It was assumed that strain gages having a zero transverse sensitivity factor were placed at the external circumference of cross section No. 1, see Fig. A.1. in Appendix A. Four arrangements of gage elements

and several numbers of Fourier coefficients were used.

The first arrangement consisted of twelve strain gage rosettes equally spaced 30° from each other around the cross section. Each rosette has three gage elements oriented at 0°, 45° and 90° from the positive tangential axis. Runs were made with 11, 9, 7, 5 and 3 Fourier coefficients for each stress component.

The second arrangement consisted of twelve rosettes spaced as above but with elements oriented at 0°, 60°, and 120°. Runs were made for the same number of Fourier coefficients.

The third arrangement consisted of eight strain rosettes equally spaced 45° from each other. The rosettes had four gage elements oriented at 0°, 45°, 90° and 135° from the positive tangential axis. Runs were made for the same number of Fourier coefficients.

As input data for testing the program, stress distributions produced by the loading were evaluated at the external circumference of cross section No. 1. From the stresses, the theoretical strain that the gage element would sense, was computed. The stress distributions recovered by the program agreed in all cases with the input information. Results using eleven Fourier coefficients (for each stress component s_T, s_L and s_{TL}) are almost identical with those using only three coefficients.

Additional runs were made using the second arrangement of gages, but eliminating arbitrarily the readings of some of them. This is what would have to be done in an actual case if some gage elements were known to have failed. Results are satisfactorily close to the preceding ones. Other runs were made using a strain gage transverse sensitivity factor of 1%. The program recovered likewise the input information.

The fourth gage arrangement had one gage element every 10° around

the circumference with different orientation for each gage. Runs were made using the same number of coefficients.

All the runs described above were repeated introducing in the gage element readings small random errors so to simulate actual situations. Calculated loadings differed from the input loadings to a degree which depended in each case on the amount of error introduced.

The program and some sample numerical results of the runs made are presented in Appendix B of this thesis.

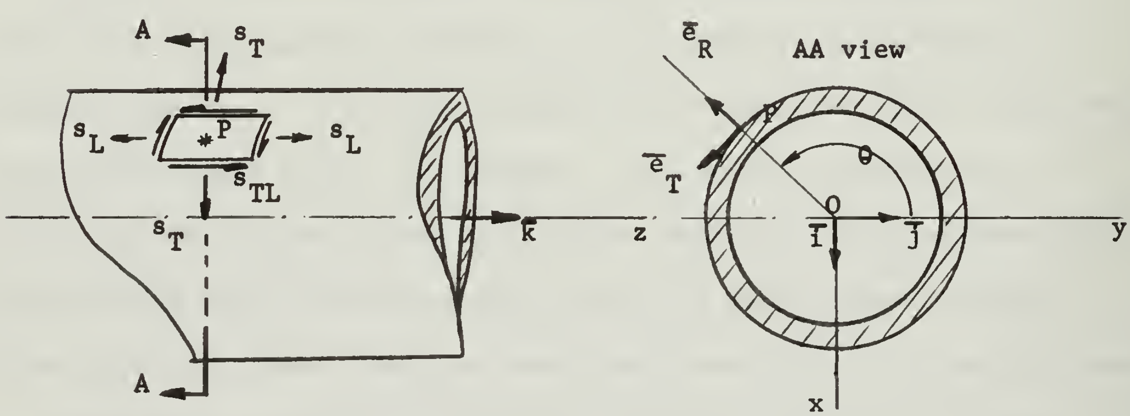
A more detailed discussion of the effects of changing the number of Fourier coefficients and gage element arrangement is presented in Appendix E.

3. Inference of the Loading Acting at a Cross Section of a Pipe of Concentric Bore from Stresses at the External Circumference of that Cross Section.

If stresses are known at a sufficient number of points around the external circumference of the cross section of a pipe of concentric bore at a distance from stress risers and concentrated loads, the loading acting at the cross section can be determined from theory.

It is intended to analyse the effects that such loads produce at a general point P under the conditions specified above. From this analysis, general conclusions will be reached which lead to a mathematical procedure to determine the loads.

Consider a cross section of pipe as specified above, Fig. 3.1. Choose reference axes x, y and z with the center point 0 as origin. Let



(a) (b)

Fig. 3.1.

$\bar{i}$, $\bar{j}$ and $\bar{k}$ be unit vectors along the positive x, y and z axis so to form a right handed triad. Let $\bar{e}_R$ be a unit vector along the outwards direction of the radius that passes through the point P, and $\bar{e}_T$ another unit vector so that $\bar{e}_R$, $\bar{e}_T$ and $\bar{k}$ form a right handed triad. The angle θ is

measured from $\bar{i}$ counterclockwise to $\bar{e}_R$. Consider the differential area surrounding the point P. Assume that tensile stresses s_T and s_L (along the directions of $\bar{e}_T$ and $\bar{k}$ respectively) and shear stress s_{TL}, are produced by internal pressure p and by a general force $\bar{F}$ and a general moment $\bar{M}$ acting on the cross section at the center point 0.

Let the components of $\bar{F}$ and $\bar{M}$ in the $\bar{e}_R$, $\bar{e}_T$ and $\bar{k}$ triad be (F_R, F_T, F_z) and (M_R, M_T, M_z) respectively, and in the $\bar{i}$, $\bar{j}$, $\bar{k}$ triad, (F_x, F_y, F_z) and (M_x, M_y, M_z).

From strength of materials considerations reviewed in reference 5, the stresses produced by p, $\bar{F}$ and $\bar{M}$ at the external point P are:

$$s_T = 2\,p\,a^2 / (b^2 - a^2) \tag{3.1}$$

$$s_L = -M_T\,b / I + F_z / A \tag{3.2}$$

$$s_{TL} = M_z\,b / (2\,I) + D\,F_T \tag{3.3}$$

where a = internal radius of the cross section

b = external radius of the cross section

A = cross sectional area

I = moment of inertia of the cross sectional area about a diameter

$D = [2\,n\,a^2 + (2n - 2)b^2] / [4I(1 + v)]$

v = Poisson's ratio

$n = v + 3/2$

Making use of the two dimensional coordinate transformation tensor

$$\begin{bmatrix} M_R \\ M_T \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} M_x \\ M_y \end{bmatrix}$$

M_T can be expressed as

$$M_T = -M_x \sin\theta + M_y \cos\theta \tag{3.4}$$

Similarly,

$$F_T = -F_x \sin\theta + F_y \cos\theta \tag{3.5}$$

The expression (3.2) for s_L can be transformed to

$$s_L = (1/A)F_z + (b/I)\sin\theta\, M_x - (b/I)\cos\theta\, M_y \tag{3.6}$$

Multiplying through by (I/b)

$$(I/b)s_L = (I/(Ab))F_z + (\sin\theta)M_x - (\cos\theta)M_y \tag{3.7}$$

Letting $(I/b) = g$, and $(I/(Ab)) = h$, both of which are cross sectional constants, substituting above and changing sides

$$h\,F_z + \sin\theta\, M_x - \cos\theta\, M_y = g\,s_L \tag{3.8}$$

The preceding theory is applicable to a point on the exterior surface of a piece of straight, uniform, concentric pipe at a sufficiently great distance from its ends or other connections which might introduce local disturbances into the stress distribution. Presuming that these conditions are satisfied, we next turn to the matter of trying to infer the loading conditions at the cross section, i.e., F_x, F_y, F_z, M_x, M_y, M_z and p, from a knowledge of the stresses at several points on the external surface of the cross section.

For a general point P, s_L and θ are known and the only unknowns in equation (3.8) are F_z, M_x and M_y. Taking three such points at the cross section, the three unknowns can be determined proceeding as follows.

Assume that the angular positions for the points are θ_1, θ_2 and θ_3 and the axial stresses are s_1, s_2 and s_3 respectively. A set of equations can then be formed

$$h\,F_z + s\theta_1\, M_x - c\theta_1\, M_y = gs_1 \tag{3.9.1}$$

$$h\,F_z + s\theta_2\, M_x - c\theta_2\, M_y = gs_2 \tag{3.9.2}$$

$$h\,F_z + s\theta_3\,M_x - c\theta_3\,M_y = gs_3 \tag{3.9.3}$$

where the letters s and c with no subscripts are abreviations for sin and cos respectively. These abbreviations will be used throughout this section.

The set of equations (3.9) is solved applying Cramer's rule

$$\text{Denominator} = \begin{vmatrix} h & s\theta_1 & -c\theta_1 \\ h & s\theta_2 & -c\theta_2 \\ h & s\theta_3 & -c\theta_3 \end{vmatrix}$$

$$= -h(\,s(\theta_1 - \theta_2) + s(\theta_2 - \theta_3) + s(\theta_3 - \theta_1)) \tag{3.10}$$

$$\text{Numerator of } F_z = \begin{vmatrix} gs_1 & s\theta_1 & -c\theta_1 \\ gs_2 & s\theta_2 & -c\theta_2 \\ gs_3 & s\theta_3 & -c\theta_3 \end{vmatrix}$$

$$= -g(\,s_1 s(\theta_2 - \theta_3) + s_2 s(\theta_3 - \theta_1) + s_3 s(\theta_1 - \theta_2)) \tag{3.11}$$

$$\text{Numerator of } M_x = \begin{vmatrix} h & gs_1 & -c\theta_1 \\ h & gs_2 & -c\theta_2 \\ h & gs_3 & -c\theta_3 \end{vmatrix}$$

$$= -hg(\,c\theta_1(s_3 - s_2) + c\theta_2(s_1 - s_3) + c\theta_3(s_2 - s_1)) \tag{3.12}$$

$$\text{Numerator of } M_y = \begin{vmatrix} h & s\theta_1 & gs_1 \\ h & s\theta_2 & gs_2 \\ h & s\theta_3 & gs_3 \end{vmatrix}$$

$$= -hg\,(s\theta_1(s_3 - s_2) + s\theta_2(s_1 - s_3) + s\theta_3(s_2 - s_1)) \tag{3.13}$$

The values of F_z, M_x and M_y are found by dividing the respective numerator by the denominator.

The remaining components of the vectors $\bar{F}$ and $\bar{M}$ appear in the expression (3.3) for s_{TL}, which by using equation (3.5) can be transformed to

$$s_{TL} = (b/2I)M_z - D\sin\theta\, F_x + D\cos\theta\, F_y \tag{3.14}$$

Multiplying through by (1/D), letting (-1/D) = g*, (-b/2ID) = h*, both cross sectional constants, substituting in (3.14) and changing sides

$$h^* M_z + \sin\theta\, F_x - \cos\theta\, F_y = g^* s_{TL} \tag{3.15}$$

This expression is of the same form as (3.8) which led to the evaluation of F_z, M_x and M_y by using information from three points. In this case the unknowns are M_z, F_x and F_y which can be evaluated by using the same three points and applying the same method. In this form the loads $\bar{F}$ and $\bar{M}$ are completely determined.

Since s_T is produced by the internal pressure p alone, it can be solved for from equation (3.1) with the information from any one of the three points used to evaluate $\bar{F}$ and $\bar{M}$

$$p = s_T(b^2 - a^2)/(2a^2) \tag{3.16}$$

From the above development, it can be concluded that theoretically the loads $\bar{F}$, $\bar{M}$ and p acting at the cross section can be determined from known stresses at three points of the external surface of the cross section.

A digital computer program called TIBISAY was developed to apply the preceding treatment. The program was tested using a mathematical model of a cantilevered pipe as in Section 2 of this thesis. Stresses generated at cross section No. 1, at points 0°, 120° and 240° from the

vertical downwards direction were used. The recovered loads were almost identical with the input ones producing the stresses. Deviations are due to small round-off errors introduced by the computer. The program and results of the test are presented in Appendix C of this thesis.

4. Conclusions.

The results obtained in the tests for applicability of the theories developed in this thesis indicate that the proposed methods can be used for analysing stresses in pipes.

There are, however, many factors influencing the validity of the results. Some of them are related to the amount of error introduced when determining geometries and material properties. Others are due to proximity to concentrated loads and stress concentrations. Other factors are directly related to the degree of redundance of strain gage data, the number of gages used and their arrangement around the cross section, and the number of Fourier coefficients to be used. Also, it may be that the least-squares method used does not produce the best results; perhaps, by minimizing some other function of error, better results could be obtained.

First steps were taken to investigate further some of these factors. Appendix E of this thesis presents results of a survey made concerning the influence of the number of Fourier coefficients used in the accuracy of results. There are also preliminary results of the influence of the number of gage elements and their arrangement around the cross section. Due to time limitations, further investigations were not conducted.

The digital computer programs included in this thesis can be used to investigate deeper into the field. Some refinements of the methods can be added. It is believed that the following points should not be neglected.:

a. Other criteria for minimizing errors can be investigated. A discussion of such criteria is given in reference 7 of this thesis. It is likely that some of the methods described there may have application in the pipe stress problem considered herein.

b. One may investigate the question of the minimum number of strain gage elements necessary to obtain acceptable stress distributions, and their orientation around the cross section. Similarly, the optimum number of elements and preferred orientation could be investigated.

c. While observing the results for a determined gage arrangement, it was noticed that good results were obtained using from 3 to 7 Fourier coefficients, but more than that produced bad results; using again 5 coefficients and changing the gage arrangement, good results were obtained for some arrangements and bad results for others. Some of these results are presented in Appendix G of this thesis. Further study could be made of the optimal number of Fourier coefficients to be employed.

d. A method for data rejection should be incorporated in the theory and computer programs. There are instances when it is obvious that a strain gage element has failed and the reading of that gage should be neglected. Usually bad gages are not easily identified and bad data is processed along with good data. There is the possibility of incorporating a data rejection procedure in the method developed in Section 2 of this thesis. One suggestion for such a procedure is given in the following.

The estimated Fourier coefficients of the stress distributions are evaluated from a minimization of the sum of the squares of the errors, i.e., the differences between the gage element readings and what they should have read theoretically. We can assume that these errors are random having a statistical normal distribution with mean and standard deviation which could be computed. Establishing a level of significance for a deviation to be sufficiently apart from the mean, one can reject the data having greater deviations and recompute the stress distributions with the remaining data. Similar screenings can be done with the

newly computed stress distributions until the remaining data have deviations under the level of rejection. This theory could be readily used if the redundance of data were large. Usually this is not the case and one must avoid rejecting data which are not perfect but which are useful and necessary. If the data is known to have a normal curve with a very sharp peak, bad data is easily determined and low significance levels can be used. If the bell is fairly flat, the majority of the deviations have pronounced deviations from the mean and the level of rejection becomes difficult to establish. The writer is inclined to think that there are criteria that may satisfy all conditions. Once they are found, the theory could be applied to this problem and to similar ones.

5. Bibliography.

1. Koch, J. W., Jr., Analysis of Strain Gage Data from Submarine MSW Piping, Thesis, Naval Postgraduate School, May 1966.

2. Timoshenko, S. and Goodier, J. N., Theory of Elasticity, McGraw-Hill Book Company, Inc., 1951.

3. Perry, C. C. and Lissner, H. R., The Strain Gage Primer, McGraw-Hill Book Company, Inc., 1962.

4. Lee, G. H., An Introduction to Experimental Stress Analysis, John Wiley and Sons, Inc., 1950.

5. Blair, N. and Brock, J. E., Sixth Progress Report, Contract N161-26327 with U. S. Naval Academy, 1967.

6. Brock, J. E., Fourth Progress Report, Contract N161-26327 with U. S. Naval Academy, 1966.

7. Villaran Tapia, C. F., Determination of Optimal Compliance and Stiffness Matrices from Experimental Data, Thesis, Naval Postgraduate School, September 1967.

APPENDIX A

DATA GENERATION THEORY AND RELATED DIGITAL COMPUTER PROGRAMS

The data used to test the applicability of the theories developed in this thesis was generated for a mathematical model of a cantilevered pipe of concentric bore subjected to internal pressure p and general force $\overline{F}$ and general moment $\overline{M}$ applied to the tip. Details of this pipe are shown in Fig. A.1. The following material properties, pipe dimensions, and loads were specified:

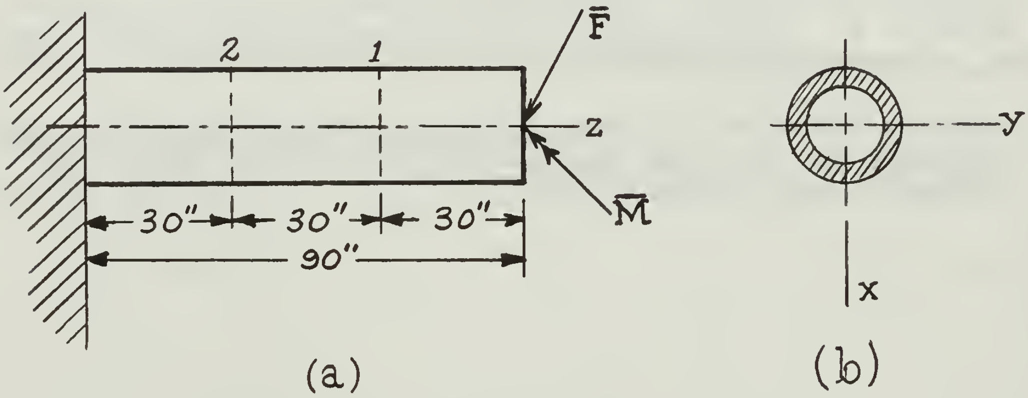


Fig. A.1.

E = 30,000 ksi

v = 0.3

Specific weight = 0.283 lb/in^3

External diameter = 12.0 in

Internal diameter = 10.0 in

$F_x = F_y = F_z = 100.0$ lb

$M_x = M_y = M_z = 100.0$ lb-in

p = 100.0 psi

Subroutine CANTIL presented herein in this Appendix, was used to evaluate the tangential, longitudinal and shear stress distributions

at the external circumference of cross sections 1 and 2 of this pipe. The stress distributions were used in turn to supply the data required for the tests specified in other parts of this thesis.

This subroutine is used by either of the (main) programs TERESITA or TIBISAY described in Appendices B and C. The arrangement of the card input is indicated in Fig. B.1. of this thesis. Description and specifications for CANTIL follow this page.

DESCRIPTION OF SUBROUTINE CANTIL

Subroutine CANTIL evaluates the state of stress at any point of a cantilevered straight pipe of concentric bore, with internal pressure and loaded at the tip by general forces and general moments. The program is capable of analysing from 1 to 360 points in each of 1 to 5 cross sections of the pipe. The points have to be at the same radial distance from the center of the pipe, and separated from one another by angular intervals which are submultiples of 360°, from 1° to 360°.

The data deck, see Fig. B.1, includes the following cards:

Card No. 1. Format 3F20.8

a. External diameter of the pipe, inches.

b. Internal diameter of the pipe, inches.

c. Pipe length, inches.

Card No. 2. Format 3E20.8, 2F10.8

a. Young's modulus of elasticity, psi.

b. Shear modulus of elasticity, psi. This can be omitted in which case it will be computed by the program from $E/2(1 + v)$.

c. Coefficient of thermal expansion. This can be omitted. It is not actually used in any present application.

d. Poisson's ratio.

e. Specific weight of the material, pounds per cubic inch.

Card No. 3. Format 2I5, 5F10.5

a. Number of points to be analysed in each cross section.

b. Number of cross sections to be analysed in the pipe.

c. The distances from the tip of the pipe to the cross sections to be analysed, inches.

Card No. 4. Format F80.2

a. Radial distance of the points to be analysed, inches.

NOTE: for applications to other parts of this thesis, evaluations are made only at the outside surface, but the program is capable of making evaluations at interior points.

Card No. 5. Format F80.2

a. Internal pressure, psi.

Card No. 6. Format 3F20.8

a. Components of the force applied at the tip of the pipe, vertical, sidewards and outwards from the tip, so as to form a right handed set of orthogonal axes, lbs.

Card No. 7. Format 3F20.8

a. Components of the moment applied at the tip of the pipe, in the same arrangement as for the forces, lb-inches.

Card No. 8. Format F80.2

a. This is a sentinel card with one number on it. A negative number indicates that the job is finished; a zero or any positive number indicates that the program will be rerun for another set of radial distance and loads, in which case, cards similar to No. 4 through 8 must follow this one.

OUTPUTS (all arguments are outputs)

RO. External radius of the pipe.

RI. Internal radius of the pipe.

XE. Young's modulus of elasticity.

G. Shear modulus of elasticity.

XNU. Poisson's ratio.

SPECW. Specific weight of the material.

D. A constant evaluated when analysing shear stresses produced by shearing forces.

XL1. A one dimensional array containing the distances from the tip to each cross section considered.

NPOINT. Number of points analysed in each cross section.

AREA. Cross sectional area of the pipe.

ALL1. A three dimensional array intended to store the stresses at any of the points, in case the points are at the external surface of the pipe; otherwise, it has no meaning.

Other subroutines which are needed and listings for which are given in this Appendix are:

TORS: used by CANTIL to compute shear stresses produced by torsional moments.

BEND: used by CANTIL to compute bending stresses.

AXIAL: used by CANTIL to compute stresses due to axial forces.

SHEAR: used by CANTIL to compute shear stresses produced by shear forces.

CROSS: computes the cross product of two vectors.

DOT: computes the dot product of two vectors.

TIMES: computes the product of a scalar and a vector.

PLUS: computes the sum of two vectors.

MINUS: computes the difference between two vectors.

TRANSF: computes the components of a vector in another angularly displaced set of axes.

METHOD.

The vectorial approach discussed in reference 5 of this thesis is used to compute stresses produced at points of the cross section by internal pressure and forces and moments acting at the centroid of that cross section.

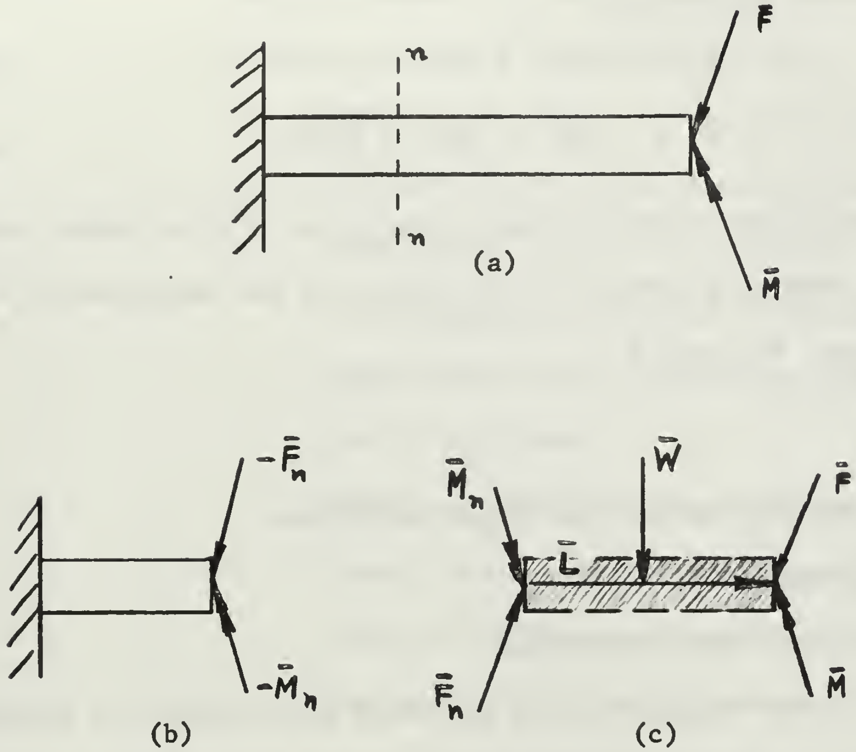


Fig. A-2.

Those forces and moments, in turn, are computed by the classical vectorial analysis of the statics of a beam. If the force $\bar{F}$ and the moment $\bar{M}$ are applied at one end of a beam, Fig. A.2.a., the force $\bar{F}_n$ and moment $\bar{M}_n$ acting at the centroid of the cross section nn, Fig. A.2.c., are found by considering the equilibrium of the segment of beam from the tip to the cross section. Summing forces and taking moments about the centroid of the cross section

$$\bar{F} + \bar{W} + \bar{F}_n = 0 \qquad (A.1)$$

$$\bar{M}_n + \bar{M} + \bar{L}x\bar{F} + \tfrac{1}{2}\bar{L}x\bar{W} = 0 \qquad (A.2)$$

where $\bar{L}$ is the vector distance from the centroid of the cross section to the point of application of the loads at the tip, and $\bar{W}$ is the force due to the weight of the segment of beam.

Solving for $\bar{F}_n$ and $\bar{M}_n$

$$\bar{F}_n = -(\bar{F} + \bar{W}) \qquad (A.3)$$

$$\bar{M}_n = -(\bar{M} + \bar{L}x\bar{F} + \tfrac{1}{2}\bar{L}x\bar{W}) \qquad (A.4)$$

The forces and moments acting at the cross section under consideration on the remaining portion of the beam, are the negatives of $\bar{F}_n$ and $\bar{M}_n$ found above, Fig. A.2.b.

PRINT-OUTS

The print-outs are several pages as follows

1st page.

a. Pipe dimensions

b. Computed cross sectional area, moment of inertia and polar moment of inertia of the cross section.

c. Material properties.

d. Number of points analysed in each cross section, number of cross sections analysed and their distances from the tip.

2nd page.

a. Radial distance of the points analysed .

b. Loads applied to the tip.

c. Distance from the tip to the first cross section analysed.

d. Computed loads acting at that cross section

Following pages. For each analysed point the print-out contains:

a. Angular position of the point in the cross section (degrees)

b. Forces and moments acting at that cross section in radial, tangential and axial components.

c. Stresses produced by individual loads.

SHTZT is the shear stress in the ZT direction produced by the axial component of the moment

SBZZ axial (ZZ direction) stress produced by the tangential component of the moment.

SAZZ axial stress produced by the axial component of the force.

SHFZR and SHFZT are stresses produced by the radial and tangential components of the force.

SPRR and SPTT are radial and tangential stresses produced by the internal pressure.

d. If the analysed points are in the external surface of the pipe, there will be additional print-outs of the total axial, tangential and shear stresses at the point.

Analysis of other cross sections for the initial and/or other radial distance and tip loads and pressure produce similar outputs as described from page 2 on. The complete program and sample outputs of the analysis made for points at the external surface and ½ in. under that surface of cross sections 1 and 2 of the pipe shown in Fig. A.1., follow this page.

```
C
      SUBROUTINE CANTIL(RO,RI,XE,G,XNU,SPECW,D,XL1,NPOINT,AREA,ALL1)
C
C TO FIND THE STATE OF STRESS AT ANY POINT, IN A CANTILIVERED STRAIGHT
C PIPE OF CONCENTRIC BORE, LOADED AT THE TIP BY GENERAL FORCES AND
C MOMENTS AND WITH INTERNAL PRESSURE.
C
      DIMENSION AF(3),AXM(3),F(3),XM(3),R(3),ER(3),ET(3),EZ(3),
     1 SHTZT(3),SBZZ(3),SAZZ(3),SHFZR(3),SHFZT(3),SPRR(3),SPTT(3)
      DIMENSION E(3,3), A1(3), A2(3), A3(3), A4(3),XL1(5), XL2(3),
     1 AXM1(3), ALL1(3,360,5),AF1(3), FWGHT(3)
C
      PRINT 500
  500 FORMAT( 1H1 )
C
C PIPE DIMENSIONS.   DO, DI, AND XL ARE EXTERNAL AND INTERNAL DIAMETERS
C AND PIPE LENGTH RESPECTIVELY.
C
      READ 50, DO, DI, XL
   50 FORMAT( 3F20.8 )
      WRITE(6, 100)  DO, DI, XL
  100 FORMAT( // 15X, 20HEXTERNAL DIAMETER  =, F8.2, 7H INCHES /
     1           15X, 20HINTERNAL DIAMETER  =, F8.2, 7H INCHES /
     2           15X, 20HLENGTH             =, F8.2, 7H INCHES /// )
C
      RO = DO/2.0
      RI = DI/2.0
      RO2 = RO*RO
      RI2 = RI*RI
      PI = 3.14159265
      AREA = PI*(RO2 - RI2 )
      ERTIA = AREA*(RO2 + RI2)/4.0
      POLER = 2.0*ERTIA
C
      WRITE(6, 103)  AREA, ERTIA, POLER
  103 FORMAT(      15X, 20HCROSSECTIONAL AREA =,  F12.4, 4H IN2 /
     1             15X, 20HMOMENT OF INERTIA  =,  F12.4, 4H IN4 /
     2             15X, 20HPOLAR MOMENT OF I. =,  F12.4, 4H IN4 /// )
C
C MATERIAL PROPERTIES.  XE IS MODULUS OF ELASTICITY. G IS SHEAR MODULUS
C OF ELASTICITY WHICH WILL BE COMPUTED IF NOT GIVEN. ALPHA IS COEFF. OF
C THERMAL EXPANSION, IF NOT GIVEN, A PRINTOUT WILL SAY SO. XNU IS
C POISSON RATIO. SPECW IS SPECIFIC WIGHT.
C
```

```
C
C
C
C
C
      READ 51,XE,G, ALPHA, XNU, SPFCW                                   CANT0440
   51 FORMAT( 3E20.8, 2F10.8 )                                          CANT0450
C                                                                       CANT0460
      PRINT 200,XE                                                      CANT0470
  200 FORMAT(15X,21HMODULUS OF ELASTICITY, 3X, E10.2, 4H PSI )          CANT0480
      IF ( G ) 3, 3, 4                                                  CANT0490
    3 G =XE/(2.0*( 1.0 + XNU ))                                         CANT0500
    4 PRINT 201, G                                                      CANT0510
  201 FORMAT(15X, 27HSHEAR MODULUS OF ELASTICITY, 3X, E10.2, 4H PSI )   CANT0520
      IF ( ALPHA ) 5, 5, 6                                              CANT0530
    5 PRINT 202                                                         CANT0540
  202 FORMAT(15X, 42HCOEFFICIENT OF THERMAL EXPANSION NOT GIVEN   )     CANT0550
      GO TO 7                                                           CANT0560
    6 PRINT 203, ALPHA                                                  CANT0570
  203 FORMAT(15X, 32HCOEFFICIENT OF THERMAL EXPANSION, 3X, E10.2,       CANT0580
     1 13H IN/IN/DEGREE )                                               CANT0590
    7 WRITE(6, 204)  XNU, SPFCW                                         CANT0600
  204 FORMAT(15X, 13HPOISSON RATIO, 3X, F6.3 /                          CANT0610
     1           15X, 15HSPECIFIC WEIGHT,3X, F8.4, 7H LB/IN3  /// )     CANT0620
C                                                                       CANT0630
C NPOINT IS THE NUMBER OF POINTS TO BE ANALYSED IN EACH CROSS SECTION.  CANT0640
C NSECT IS THE NUMBER OF CROSS SECTIONS TO BE ANALYSED. XL1 IS ONE      CANT0650
C DIMENSIONAL ARRAY CONTAINING THE DISTANCES OF THE CROSS SECTIONS FROM CANT0660
C THE TIP.                                                              CANT0670
C                                                                       CANT0680
      READ 54, NPOINT, NSECT, XL1                                       CANT0690
   54 FORMAT(2I5, 5F10.5  )                                             CANT0700
C                                                                       CANT0710
      WRITE(6, 700)  NPOINT, NSECT, XL1                                 CANT0720
  700 FORMAT(15X, 'NUMBER OF POINTS TO ANALYSE  ', I5 /                 CANT0730
     1           15X, 29HNUMBER OF SECTIONS TO ANALYZE, I5  /           CANT0740
     2           15X, 'DISTANCES FROM THE TIP TO THE CROSS SECTIONS, INCHESCANT0750
     3 ', // 20X, 5F8.3  )                                              CANT0760
C                                                                       CANT0770
C                                                                       CANT0780
C                                                                       CANT0790
C UNIT VECTORS IN POLAR DIRECTIONS                                      CANT0800
C                                                                       CANT0810
      ER(1) = 1.0                                                       CANT0820
      ER(2) = 0.0                                                       CANT0830
      ER(3) = 0.0                                                       CANT0840
      ET(1) = 0.0                                                       CANT0850
      ET(2) = 1.0                                                       CANT0860
```

```
C
      ET(3) = 0.0
      EZ(1) = 0.0
      EZ(2) = 0.0
      EZ(3) = 1.0
C
C
C DELTA IS THE ANGULAR INTERVAL IN DEGREES BETWEEN POINTS. R IS THE POS-
C ITION VECTOR OF THE POINT TO BE ANALYSED TAKING AS CENTER THE CENTER
C OF THE CROSS SECTION.  XL2 IS THE DISTANCE VECTOR FROM THE CENTER OF
C THE CROSS SECTION TO THE TIP.
C
      DELTA = 360/NPOINT
      THETA2 = PI/180.0
C
    8 READ 900, R(1)
  900 FORMAT( F80.2 )
      R(2) = 0.0
      R(3) = 0.0
      XL2(1) = 0.0
      XL2(2) = 0.0
C
C LOADS APPLIED IN VERTICAL DOWNWARDS (1), TRANSVERSE (2) AND AXIALLY
C OUTWARDS FROM THE TIP (3) DIRECTIONS.  P IS THE INTERNAL PRESSURE.
C AF1 AND AXM1 ARE THE GENERAL FORCE AND GENERAL MOMENT ACTING AT THE
C TIP.
C
      READ(5, 52)  P, AF1, AXM1
   52 FORMAT( F80.2 / 3F20.8 / 3F20.8 )
C
C
C
      DO 11  J = 1, NSECT
C
      PRINT 500
      PRINT 901, R(1)
  901 FORMAT(//15X,'RADIAL DISTANCE OF POINTS =',F12.5,' INCHES'///)
C
      PRINT 800
  800 FORMAT(15X,    24HLOADS APPLIED TO THE TIP, / )
      WRITE(6, 302)  P, AF1, AXM1
  302 FORMAT(     15X, 20HINTERNAL PRESSURE   =,F12.2, 4H PSI /
     1            15X, 20HAPPLIED FORCE       =, 3F12.2, 3H LB /
     2            15X, 20HAPPLIED MOMENT      =, 3F12.2, 6H LB-IN /// )
```

```
C
      XL2(3) = XL1(J)
      PRINT 305, XL2(3)
  305 FORMAT(15X,'DISTANCE FROM THE TIP TO THE CROSS SECTION',F10.2,
     1 ' INCHES' )
C
      PRINT 801
  801 FORMAT(//15X,'LOADS ACTING ON THE CROSS SECTION')
C
C FWGHT IS THE FORCE DUE TO THE WEIGHT OF THE PIPE FROM THE TIP TO THE
C CROSS SECTION.  AF AND AXM ARE THE LOADS ACTING ON THE CROSS SECTION.
C
      FWGHT(1) = AREA*SPECW*XL2(3)
      FWGHT(2) = 0.0
      FWGHT(3) = 0.0
      CALL PLUS( FWGHT, AF1, AF )
      CALL CROSS( XL2, AF1, A1 )
      CALL PLUS( AXM1, A1, AXM )
      CALL TIMES( 0.5, XL2, A2 )
      CALL CROSS( A2, FWGHT, A3 )
      CALL PLUS ( AXM, A3, AXM )
C
      WRITE(6, 302)  P, AF, AXM
C
      INDEX = 1
      WRITE(6, 500)
C
      DO 1   I = 1, NPOINT
      AI = I
C
      IF( INDEX .LE.  4 )  GO TO 25
      INDEX = 1
      WRITE(6, 500)
   25 INDEX = INDEX + 1
C
C THETA1 IS THE ANGLE IN DEGREES FROM THE DOWNWARDS DIRECTION TO THE
C POINT TO BE ANALYSED, IN THE POSITIVE CCW DIRECTION. F AND XM ARE
C THE FORCE AND MOMENT ACTING ON THE CROSS SECTION, WITH COMPONENTS IN
C THE POLAR DIRECTIONS.
C
      THETA1 = (AI - 1.0)*DELTA
      PRINT 21, THETA1
   21 FORMAT( ///    15X, 7HTHETA =, F8.2, 3X, 7HDEGREES )
C
```

```
C
C
C
C
C
      THETA = THETA1*THETA2                                              CANT1730
C                                                                        CANT1740
      CALL TRANSF( AF, THETA, F )                                        CANT1750
      CALL TRANSF(AXM, THETA, XM )                                       CANT1760
C                                                                        CANT1770
      WRITE(6, 600)  F, XM                                               CANT1780
  600 FORMAT(     15X, 20HTRANSFORMED FORCE  =, 3E12.5, 3H LB /          CANT1790
     1            15X, 20HTRANSFORMED MOMENT =, 3E12.5, 6H LB-IN / )     CANT1800
C                                                                        CANT1810
C SHTZT IS THE SHEAR STRESS IN THE ZT DIRECTION PRODUCED BY THE TORS-    CANT1820
C IONAL MOMENT.  SBZZ IS THE STRESS IN THE AXIAL ZZ DIRECTION  PRODUCED CANT1830
C BY THE BENDING MOMENTS. SAZZ IS STRESS IN THE AXIAL ZZ DIRECTION PROD-CANT1840
C UCED BY THE AXIAL FORCE.  SHFZR AND SHFZT ARE THE SHEAR STRESSES PROD-CANT1850
C UCED IN IN THE ZR AND ZT DIRECTIONS BY THE SHEAR FORCES.  SPRR AND     CANT1860
C SPTT ARE THE STRESSES IN THE RADIAL RR AND TANGENTIAL TT DIRECTIONS    CANT1870
C PRODUCED BY THE INTERNAL PRESSURE.                                     CANT1880
C                                                                        CANT1890
      CALL TORS(XM, R, EZ, ERTIA, SHTZT )                                CANT1900
C                                                                        CANT1910
      CALL BEND( XM, R, EZ, ERTIA, SBZZ )                                CANT1920
C                                                                        CANT1930
      CALL AXIAL( F, EZ, AREA, SAZZ )                                    CANT1940
C                                                                        CANT1950
      CALL SHEAR( F,R,ER,ET,ERTIA,XNU,RI2,RO2,SHFZR,SHFZT,D)             CANT1960
C                                                                        CANT1970
      CALL PRESS(P, R, RI2, RO2, SPRR, SPTT )                            CANT1980
C                                                                        CANT1990
      WRITE(6, 22)  SHTZT(2),SBZZ(3),SAZZ(3),SHFZR(1),SHFZT(2),          CANT2000
     1 SPRR(1),SPTT(2)                                                   CANT2010
   22 FORMAT(15X, 5HSHTZT,  E17.5 /                                      CANT2020
     1        15X, 5HS BZZ,  E17.5 /                                     CANT2030
     2        15X, 5HS AZZ,  E17.5 /                                     CANT2040
     3        15X, 5HSHFZR,  E17.5 /                                     CANT2050
     4        15X, 5HSHFZT,  E17.5 /                                     CANT2060
     5        15X, 5HS PRR,  E17.5 /                                     CANT2070
     6        15X, 5HS PTT,  E17.5 )                                     CANT2080
C                                                                        CANT2090
      IF( R(1) - RO )   1001, 1002, 1001                                 CANT2100
 1002 CONTINUE                                                           CANT2110
C                                                                        CANT2130
C                                                                        CANT2120
C ALL1 IS AN ARRAY INTENDED TO MEMORIZE THE STRESSES AT ANY ONE OF THE  CANT2140
C POINTS IN CASE THOSE POINTS ARE AT THE EXTERNAL SURFACE OF THE PIPE,  CANT2150
```

```
C
C OTHERWISE, IT HAS NO MEANING.
C ALL1(1...) ARE STRESSES IN THE TANGENTIAL TT DIRECTION.
C ALL1(2...) ARE STRESSES IN THE AXIAL ZZ DIRECTION.
C ALL1(3...) ARE SHEAR STRESSES IN THE ZT DIRECTION.
C
        ALL1(1,I,J) = SPTT(2)
        ALL1(2,I,J) = SBZZ(3) + SAZZ(3)
        ALL1(3,I,J) = SHFZT(2) + SHTZT(2)
C
        PRINT 31
   31   FORMAT(/ 27X, 13HT'T DIRECTION, 4X, 13HZ'Z DIRECTION, 4X, 13HZ'T
     1DIRECTION  )
C
        PRINT 32, ( K, I, J,   K = 1, 3  )
   32   FORMAT( 28X, 3( 5HALL1(, I1, 1H,, I2, 1H,, I1, 1H),5X)  )
C
        PRINT 33, ( ALL1( K, I, J ) , K = 1, 3 )
   33   FORMAT( 15X, 'STRESSES', E16.5, 2E17.5 )
C
 1001   CONTINUE
C
    1   CONTINUE
C
   11   CONTINUE
C
C
C FIN IS A SENTINEL CARD. WHEN NOT NEGATIVE ( MAY BE A BLANK CARD ) THEN
C OTHER SET OF RADIAL DISTANCE AND TIP LOADS WILL BE READ AND THE
C PROGRAM WILL RERUN.  IF FIN IS A NEGATIVE NUMBER, THE PROGRAM WILL
C PROCEDE TO THE NEXT STEP.
C
        READ 501, FIN
  501   FORMAT( F80.5 )
C
        IF ( FIN ) 999, 8, 8
  999   CONTINUE
        RETURN
        END
```

```
C
      SUBROUTINE TORS(XM,R, EZ, ERTIA, STZT )                           TORS0010
C                                                                       TORS0020
C TO FIND THE SHEAR STRESS PRODUCED BY THE TORSIONAL COMPONENT OF THE   TORS0030
C APPLIED MOMENT XM.R IS THE POSITION VECTOR OF THE POINT TO BE ANALYZEDTORS0040
C  EZ IS UNIT VECTOR IN THE AXIAL DIRECTION. ERTIA IS THE MOMENT OF IN- TORS0050
C ERTIA. STZT IS THE PRODUCED SHEAR STRESS IN THE ZT DIRECTION.         TORS0060
C                                                                       TORS0070
      DIMENSION  XM(3), R(3), A1(3), EZ(3), STZT(3)                     TORS0080
      CALL CROSS( EZ, R, A1 )                                           TORS0090
      CALL DOT(XM, EZ, Z )                                              TORS0100
      CALL TIMES( Z/(2.0*ERTIA), A1, STZT )                             TORS0110
      RETURN                                                            TORS0120
      END                                                               TORS0130
```

```
C
      SUBROUTINE BEND(XM, R, EZ, ERTIA, SBZZ )                          BEND0010
C                                                                       BEND0020
C TO FIND THE STRESSES PRODUCED BY THE BENDING COMPONENT OF THE APPLIED BEND0030
C MOMENT XM. R IS THE POSITION VECTOR OF THE POINT TO BE ANALYZED.  EZ  BEND0040
C IS UNIT VECTOR IN THE AXIAL DIRECTION.  ERTIA IS MOMENT OF INERTIA.   BEND0050
C SBZZ IS STRESS PRODUCED IN THE AXIAL ZZ DIRECTION.                    BEND0060
C                                                                       BEND0070
      DIMENSION  XM(3), R(3), EZ(3), A1(3), SBZZ(3)                     BEND0080
      CALL CROSS( R, EZ, A1 )                                           BEND0090
      CALL DOT( A1, XM, Z )                                             BEND0100
      CALL TIMES( Z/ERTIA, EZ, SBZZ )                                   BEND0110
      RETURN                                                            BEND0120
      END                                                               BEND0130
```

```
C
      SUBROUTINE AXIAL( F, EZ, AREA, SAZZ )
C
C TO FIND THE STRESSES PRODUCED BY THE AXIAL COMPONENT OF THE APPLIED
C FORCE F. FZ IS UNIT VECTOR IN THE AXIAL DIRECTION.  AREA IS THE AREA
C OF THE CROSS SECTION. SAZZ IS THE STRESS PRODUCED IN THE AXIAL ZZ
C DIRECTION
C
      DIMENSION F(3), EZ(3), A1(3), SAZZ(3)
      CALL DOT( F, EZ, Z )
      CALL TIMES( Z/AREA, EZ, SAZZ )
      RETURN
      END
```

```
C
      SUBROUTINE SHEAR(F,R,ER,ET,ERTIA,XNU,RI2,RO2,SHFRZ,SHFTZ, D )
C
C TO FIND THE SHEAR PRODUCED BY THE TRANSVERSE COMPONENTS OF THE APPLIED
C FORCE F.  R IS POSITION VECTOR OF THE POINT TO BE ANALYZED.  ER AND
C ET ARE UNIT VECTORS IN THE RADIAL AND TANGENTIAL DIRECTIONS.  ERTIA
C IS MOMENT OF INERTIA OF THE CROSS SECTION.  XNU IS POISSON RATIO. RI2
C AND RO2 ARE THE SQUARE OF THE INTERNAL AND EXTERNAL RADIUS OF THE
C CROSS SECTION.  SHFRZ AND SHFTZ ARE THE SHEAR STRESSES PRODUCED IN THE
C RZ AND TZ DIRECTIONS. D IS A PARAMETER OUTPUT TO BE USED SOMEWHERE
C ELSE.
C
      DIMENSION F(3),R(3),ER(3),ET(3),SHFRZ(3),SHFTZ(3)
      CALL DOT( R, R, R2 )
      ENE =XNU + 1.5
      ALPHA = ENE*( RI2 + RO2 ) - R2
      BETA = ENE*( R2 + RI2*RO2/R2 ) - R2
      Z1 = 4.0*ERTIA*( 1.0 +XNU )
      C = ( BETA - ALPHA )/Z1
      D = ( BETA + ALPHA )/Z1
      CALL DOT( F, ER, Z )
      CALL TIMES( -C*Z, ER, SHFRZ )
      CALL DOT( F, ET, Z )
      CALL TIMES( D*Z, ET, SHFTZ )
      RETURN
      END
```

```
C
      SUBROUTINE PRESS(P, R, RI2, RO2, SPRR, SPTT )
C
C TO FIND THE STRESSES IN THE RADIAL AND TANGENTIAL DIRECTIONS PRODUCED
C BYTHE INTERNAL PRESSURE P.  R IS THE POSITION VECTOR OF THE POINT TO
C BE ANALYZED.  RI2 AND RO2 ARE THE SQUARE OF THE INTERNAL AND EXTERNAL
C RADIUS OF THE CROSS SECTION. SPRR AND SPTT ARE THE STRESSES PRODUCED
C IN THE RADIAL AND TANGENTIAL DIRECTIONS.
C
      DIMENSION SPRR(3), SPTT(3), R(3)
      CALL DOT( R, R, R2 )
      Z = P*RI2/(RO2 - RI2 )
      Z1 = RO2/R2
      SPRR(1) = Z*( 1.0 - Z1 )
      SPTT(2) = Z*( 1.0 + Z1 )
      SPRR(2) = 0.0
      SPRR(3) = 0.0
      SPTT(1) = 0.0
      SPTT(3) = 0.0
      RETURN
      END
```

```
C
      SUBROUTINE CROSS( A, B, C )
C
C VECTOR PRODUCT OF VECTORS A AND B RESULTING VECTOR C.
C
      DIMENSION A(3), B(3), C(3)
      C(1) = A(2)*B(3) - A(3)*B(2)
      C(2) = -A(1)*B(3) + A(3)*B(1)
      C(3) = A(1)*B(2) - A(2)*B(1)
      RETURN
      END
```

```
C
      SUBROUTINF DOT( A, B, C )                                          DOT 0010
C                                                                        DOT 0020
C SCALAR PRODUCT OF VECTORS A AND B RESULTING C.                         DOT 0030
C                                                                        DOT 0040
      DIMFNSION A(3), B(3)                                               DOT 0050
      C          = A(1)*B(1) +A(2)*B(2) + A(3)*B(3)                      DOT 0060
      RETURN                                                             DOT 0070
      END                                                                DOT 0080
```

```
C
      SUBROUTINE TIMES( A, B, C )
C
C MULTIPLICATION OF THE SCALAR A WITH THE VECTOR B RESULTING VECTOR C.
C
      DIMENSION B(3), C(3)
      DO 1  J = 1,3
    1 C(J) = A*B(J)
      RETURN
      END
```

```
      SUBROUTINE PLUS( A, B, C )                                        PLUS0010
C                                                                       PLUS0020
C ADD VECTORS A AND B RESULTING C.                                      PLUS0030
C                                                                       PLUS0040
      DIMENSION A(3), B(3), C(3)                                        PLUS0050
      DO 1  J = 1,3                                                     PLUS0060
    1 C(J) = A(J) + B(J)                                                PLUS0070
      RETURN                                                            PLUS0080
      END                                                               PLUS0090
```

```
C
      SUBROUTINE MINUS(A, B, C)                                         MINU0010
C                                                                       MINU0020
C SUBSTRACT VECTOR B FROM VECTOR A RESULTING VECTOR C.                  MINU0030
C                                                                       MINU0040
      DIMENSION A(3), B(3), C(3)                                        MINU0050
      DO 1    J = 1, 3                                                  MINU0060
    1 C(J) = A(J) - B(J)                                                MINU0070
      RETURN                                                            MINU0080
      END                                                               MINU0090
```

```
C
      SUBROUTINE TRANSF(A, THETA, C )                                   TRAN0010
C                                                                       TRAN0020
C  TO FIND COMPONENTS OF VECTOR A IN OTHER AXIS ROTATED BY AN ANGLE    TRAN0030
C  THETA.  A IS CALLED C IN THE NEW AXIS.                               TRAN0040
C                                                                       TRAN0050
      DIMENSION A(3), E(3,3), C(3)                                      TRAN0060
      E(1,1) = COS(THETA)                                               TRAN0070
      E(2,1) = SIN(THETA)                                               TRAN0080
      E(3,1 ) = 0.0                                                     TRAN0090
      E(1,2) = -SIN(THETA)                                              TRAN0100
      E(2,2) = COS(THETA)                                               TRAN0110
      E(3,2) = 0.0                                                      TRAN0120
      E(1,3) = 0.0                                                      TRAN0130
      E(2,3) = 0.0                                                      TRAN0140
      E(3,3) =1.0                                                       TRAN0150
      DO 1   I = 1,3                                                    TRAN0160
      C(I) = 0.0                                                        TRAN0170
      DO 1   J = 1, 3                                                   TRAN0180
    1 C(I) = C(I) + A(J)*E(J,I)                                         TRAN0190
      RETURN                                                            TRAN0200
      END                                                               TRAN0210
```

```
EXTERNAL DIAMETER   =   12.00 INCHES
INTERNAL DIAMETER   =   10.00 INCHES
LENGTH              =   90.00 INCHES


CROSSECTIONAL AREA =     34.5575 IN2
MOMENT OF INERTIA  =    527.0020 IN4
POLAR MOMENT OF I. =   1054.0039 IN4


MODULUS OF ELASTICITY      0.30E 08 PSI
SHEAR MODULUS OF ELASTICITY      0.12E 08 PSI
COEFFICIENT OF THERMAL EXPANSION NOT GIVEN
POISSON RATIO     0.300
SPECIFIC WEIGHT      0.2830 LB/IN3


NUMBER OF POINTS TO ANALYSE      12
NUMBER OF SECTIONS TO ANALYZE     2
DISTANCES FROM THE TIP TO THE CROSS SECTIONS, INCHES

        30.000  60.000   0.0      0.0      0.0
```

```
RADIAL DISTANCE OF POINTS =     6.00000 INCHES


LOADS APPLIED TO THE TIP

INTERNAL PRESSURE  =       100.00 PSI
APPLIED FORCE      =       100.00        100.00        100.00 LB
APPLIED MOMENT     =       100.00        100.00        100.00 LB-IN


DISTANCE FROM THE TIP TO THE CROSS SECTION     30.00 INCHES


LOADS ACTING ON THE CROSS SECTION
INTERNAL PRESSURE  =       100.00 PSI
APPLIED FORCE      =       393.39        100.00        100.00 LB
APPLIED MOMENT     =     -2900.00       7500.89        100.00 LB-IN
```

```
THETA =     0.0      DEGREES
TRANSFORMED FORCE   = 0.39339E 03 0.10000E 03 0.10000E 03 LB
TRANSFORMED MOMENT =-0.29000E 04 0.75009E 04 0.10000E 03 LB-IN

SHTZT          0.56926E 00
S BZZ         -0.35399E 02
S AZZ          0.28937E 01
SHEZR          0.0
SHEZT          0.53861E 01
S PRR          0.0
S PTT          0.45455E 03

               T'T DIRECTION      Z'Z DIRECTION      Z'T DIRECTION
                ALL1(1, 1,1)       ALL1(2, 1,1)       ALL1(3, 1,1)
STRESSES        0.45455E 03       -0.82505E 02        0.59553E 01


THETA =    30.00     DEGREES
TRANSFORMED FORCE   = 0.39069E 03-0.11009E 03 0.10000E 03 LB
TRANSFORMED MOMENT = 0.12390E 04 0.79460E 04 0.10000E 03 LB-IN

SHTZT          0.56926E 00
S BZZ         -0.90466E 02
S AZZ          0.28937E 01
SHEZR          0.0
SHEZT         -0.59297E 01
S PRR          0.0
S PTT          0.45455E 03

               T'T DIRECTION      Z'Z DIRECTION      Z'T DIRECTION
                ALL1(1, 2,1)       ALL1(2, 2,1)       ALL1(3, 2,1)
STRESSES        0.45455E 03       -0.87572E 02       -0.53605E 01


THETA =    60.00     DEGREES
TRANSFORMED FORCE   = 0.28330E 03-0.29069E 03 0.10000E 03 LB
TRANSFORMED MOMENT = 0.50460E 04 0.62619E 04 0.10000E 03 LB-IN

SHTZT          0.56926E 00
S BZZ         -0.71293E 02
S AZZ          0.28937E 01
SHEZR          0.0
SHEZT         -0.15657E 02
S PRR          0.0
S PTT          0.45455E 03

               T'T DIRECTION      Z'Z DIRECTION      Z'T DIRECTION
                ALL1(1, 3,1)       ALL1(2, 3,1)       ALL1(3, 3,1)
STRESSES        0.45455E 03       -0.68399E 02       -0.15087E 02


THETA =    90.00     DEGREES
TRANSFORMED FORCE   = 0.10000E 03-0.39339E 03 0.10000E 03 LB
TRANSFORMED MOMENT = 0.75009E 04 0.29000E 04 0.10000E 03 LB-IN

SHTZT          0.56926E 00
S BZZ         -0.33017E 02
S AZZ          0.28937E 01
SHEZR          0.0
SHEZT         -0.21188E 02
S PRR          0.0
S PTT          0.45455E 03

               T'T DIRECTION      Z'Z DIRECTION      Z'T DIRECTION
                ALL1(1, 4,1)       ALL1(2, 4,1)       ALL1(3, 4,1)
STRESSES        0.45455E 03       -0.30123E 02       -0.20619E 02
```

```
THETA =   120.00    DEGREES
TRANSFORMED FORCE   =-0.11009E 03-0.39069E 03 0.10000E 03 LB
TRANSFORMED MOMENT = 0.79460E 04-0.12390E 04 0.10000E 03 LB-IN

SHTZT          0.56926E 00
S BZZ          0.14106E 02
S AZZ          0.28937E 01
SHEZR          0.0
SHEZT         -0.21043E 02
S PRR          0.0
S PTT          0.45455E 03

              T'T DIRECTION       Z'Z DIRECTION       Z'T DIRECTION
               ALL1(1, 5,1)        ALL1(2, 5,1)        ALL1(3, 5,1)
STRESSES       0.45455E 03         0.16999E 02        -0.20473E 02


THETA =   150.00    DEGREES
TRANSFORMED FORCE   =-0.29069E 03-0.28330E 03 0.10000E 03 LB
TRANSFORMED MOMENT = 0.62619E 04-0.50460E 04 0.10000E 03 LB-IN

SHTZT          0.56926E 00
S BZZ          0.57449E 02
S AZZ          0.28937E 01
SHEZR          0.0
SHEZT         -0.15259E 02
S PRR          0.0
S PTT          0.45455E 03

              T'T DIRECTION       Z'Z DIRECTION       Z'T DIRECTION
               ALL1(1, 6,1)        ALL1(2, 6,1)        ALL1(3, 6,1)
STRESSES       0.45455E 03         0.60343E 02        -0.14689E 02


THETA =   180.00    DEGREES
TRANSFORMED FORCE   =-0.39339E 03-0.10000E 03 0.10000E 03 LB
TRANSFORMED MOMENT = 0.29000E 04-0.75009E 04 0.10000E 03 LB-IN

SHTZT          0.56926E 00
S BZZ          0.85399E 02
S AZZ          0.28937E 01
SHEZR          0.0
SHEZT         -0.53861E 01
S PRR          0.0
S PTT          0.45455E 03

              T'T DIRECTION       Z'Z DIRECTION       Z'T DIRECTION
               ALL1(1, 7,1)        ALL1(2, 7,1)        ALL1(3, 7,1)
STRESSES       0.45455E 03         0.88292E 02        -0.48168E 01


THETA =   210.00    DEGREES
TRANSFORMED FORCE   =-0.39069E 03 0.11009E 03 0.10000E 03 LB
TRANSFORMED MOMENT =-0.12390E 04-0.79460E 04 0.10000E 03 LB-IN

SHTZT          0.56926E 00
S BZZ          0.90466E 02
S AZZ          0.28937E 01
SHEZR          0.0
SHEZT          0.59297E 01
S PRR          0.0
S PTT          0.45455E 03

              T'T DIRECTION       Z'Z DIRECTION       Z'T DIRECTION
               ALL1(1, 8,1)        ALL1(2, 8,1)        ALL1(3, 8,1)
STRESSES       0.45455E 03         0.93360E 02         0.64989E 01
```

```
THETA =  240.00    DEGREES
TRANSFORMED FORCE   =-0.28330E 03 0.29069E 03 0.10000E 03 LB
TRANSFORMED MOMENT =-0.50459E 04-0.62619E 04 0.10000E 03 LB-IN

SHTZT         0.56926E 00
S BZZ         0.71293E 02
S AZZ         0.28937E 01
SHFZR         0.0
SHFZT         0.15657E 02
S PRR         0.0
S PTT         0.45455E 03

               T'T DIRECTION      Z'Z DIRECTION      Z'T DIRECTION
                ALL1(1, 9,1)       ALL1(2, 9,1)       ALL1(3, 9,1)
STRESSES        0.45455E 03        0.74187E 02        0.16226E 02


THETA =  270.00    DEGREES
TRANSFORMED FORCE   =-0.10000E 03 0.39339E 03 0.10000E 03 LB
TRANSFORMED MOMENT =-0.75009E 04-0.29000E 04 0.10000E 03 LB-IN

SHTZT         0.56926E 00
S BZZ         0.33017E 02
S AZZ         0.28937E 01
SHFZR         0.0
SHFZT         0.21188E 02
S PRR         0.0
S PTT         0.45455E 03

               T'T DIRECTION      Z'Z DIRECTION      Z'T DIRECTION
                ALL1(1,10,1)       ALL1(2,10,1)       ALL1(3,10,1)
STRESSES        0.45455E 03        0.35911E 02        0.21758E 02


THETA =  300.00    DEGREES
TRANSFORMED FORCE   = 0.11009E 03 0.39069E 03 0.10000E 03 LB
TRANSFORMED MOMENT =-0.79460E 04 0.12390E 04 0.10000E 03 LB-IN

SHTZT         0.56926E 00
S BZZ        -0.14106E 02
S AZZ         0.28937E 01
SHFZR         0.0
SHFZT         0.21043E 02
S PRR         0.0
S PTT         0.45455E 03

               T'T DIRECTION      Z'Z DIRECTION      Z'T DIRECTION
                ALL1(1,11,1)       ALL1(2,11,1)       ALL1(3,11,1)
STRESSES        0.45455E 03       -0.11212E 02        0.21612E 02


THETA =  330.00    DEGREES
TRANSFORMED FORCE   = 0.29069E 03 0.28330E 03 0.10000E 03 LB
TRANSFORMED MOMENT =-0.62619E 04 0.50459E 04 0.10000E 03 LB-IN

SHTZT         0.56926E 00
S BZZ        -0.57449E 02
S AZZ         0.28937E 01
SHFZR         0.0
SHFZT         0.15259E 02
S PRR         0.0
S PTT         0.45455E 03

               T'T DIRECTION      Z'Z DIRECTION      Z'T DIRECTION
                ALL1(1,12,1)       ALL1(2,12,1)       ALL1(3,12,1)
STRESSES        0.45455E 03       -0.54555E 02        0.15828E 02
```

```
RADIAL DISTANCE OF POINTS =     6.00000 INCHES

LOADS APPLIED TO THE TIP

INTERNAL PRESSURE  =        100.00 PSI
APPLIED FORCE      =        100.00         100.00         100.00 LB
APPLIED MOMENT     =        100.00         100.00         100.00 LB-IN

DISTANCE FROM THE TIP TO THE CROSS SECTION      60.00 INCHES

LOADS ACTING ON THE CROSS SECTION
INTERNAL PRESSURE  =        100.00 PSI
APPLIED FORCE      =        686.79         100.00         100.00 LB
APPLIED MOMENT     =      -5900.00       23703.59         100.00 LB-IN
```

```
THETA =     0.0     DEGREES
TRANSFORMED FORCE   = 0.68679E 03 0.10000E 03 0.10000E 03 LB
TRANSFORMED MOMENT =-0.59000E 04 0.23704E 05 0.10000E 03 LB-IN

SHTZT        0.56926E 00
S BZZ       -0.26987E 03
S AZZ        0.28937E 01
SHFZR        0.0
SHFZT        0.53861E 01
S PRR        0.0
S PTT        0.45455E 03

              T'T DIRECTION      Z'Z DIRECTION      Z'T DIRECTION
               ALL1(1, 1,2)       ALL1(2, 1,2)       ALL1(3, 1,2)
STRESSES       0.45455E 03       -0.26698E 03        0.59553E 01


THETA =    30.00    DEGREES
TRANSFORMED FORCE   = 0.64477E 03-0.25679E 03 0.10000E 03 LB
TRANSFORMED MOMENT = 0.67422E 04 0.23478E 05 0.10000E 03 LB-IN

SHTZT        0.56926E 00
S BZZ       -0.26730E 03
S AZZ        0.28937E 01
SHFZR        0.0
SHFZT       -0.13831E 02
S PRR        0.0
S PTT        0.45455E 03

              T'T DIRECTION      Z'Z DIRECTION      Z'T DIRECTION
               ALL1(1, 2,2)       ALL1(2, 2,2)       ALL1(3, 2,2)
STRESSES       0.45455E 03       -0.26441E 03       -0.13262E 02


THETA =    60.00    DEGREES
TRANSFORMED FORCE   = 0.43000E 03-0.54477E 03 0.10000E 03 LB
TRANSFORMED MOMENT = 0.17578E 05 0.16961E 05 0.10000E 03 LB-IN

SHTZT        0.56926E 00
S BZZ       -0.19311E 03
S AZZ        0.28937E 01
SHFZR        0.0
SHFZT       -0.29342E 02
S PRR        0.0
S PTT        0.45455E 03

              T'T DIRECTION      Z'Z DIRECTION      Z'T DIRECTION
               ALL1(1, 3,2)       ALL1(2, 3,2)       ALL1(3, 3,2)
STRESSES       0.45455E 03       -0.19021E 03       -0.28773E 02


THETA =    90.00    DEGREES
TRANSFORMED FORCE   = 0.10000E 03-0.68679E 03 0.10000E 03 LB
TRANSFORMED MOMENT = 0.23704E 05 0.59000E 04 0.10000E 03 LB-IN

SHTZT        0.56926E 00
S BZZ       -0.67173E 02
S AZZ        0.28937E 01
SHFZR        0.0
SHFZT       -0.36991E 02
S PRR        0.0
S PTT        0.45455E 03

              T'T DIRECTION      Z'Z DIRECTION      Z'T DIRECTION
               ALL1(1, 4,2)       ALL1(2, 4,2)       ALL1(3, 4,2)
STRESSES       0.45455E 03       -0.64279E 02       -0.36421E 02
```

```
RADIAL DISTANCE OF POINTS =      5.50000 INCHES

LOADS APPLIED TO THE TIP

INTERNAL PRESSURE   =       100.00 PSI
APPLIED FORCE       =       100.00        100.00        100.00 LB
APPLIED MOMENT      =       100.00        100.00        100.00 LB-IN

DISTANCE FROM THE TIP TO THE CROSS SECTION     30.00 INCHES

LOADS ACTING ON THE CROSS SECTION
INTERNAL PRESSURE   =       100.00 PSI
APPLIED FORCE       =       393.39        100.00        100.00 LB
APPLIED MOMENT      =     -2900.00       7500.89        100.00 LB-IN
```

```
THETA =  120.00   DEGREES
TRANSFORMED FORCE  =-0.11009E 03-0.39069E 03 0.10000E 03 LB
TRANSFORMED MOMENT = 0.79460E 04-0.12390E 04 0.10000E 03 LB-IN

SHTZT        0.52182E 00
S BZZ        0.12930E 02
S AZZ        0.28937E 01
SHEZR       -0.72164E-01
SHEZT       -0.22426E 02
S PRR       -0.43201E 02
S PTT        0.49775E 03


THETA =  150.00   DEGREES
TRANSFORMED FORCE  =-0.29069E 03-0.28330E 03 0.10000E 03 LB
TRANSFORMED MOMENT = 0.62619E 04-0.59460E 04 0.10000E 03 LB-IN

SHTZT        0.52182E 00
S BZZ        0.52662E 02
S AZZ        0.28937E 01
SHEZR       -0.19054E 00
SHEZT       -0.16262E 02
S PRR       -0.43201E 02
S PTT        0.49775E 03


THETA =  180.00   DEGREES
TRANSFORMED FORCE  =-0.39339E 03-0.10000E 03 0.10000E 03 LB
TRANSFORMED MOMENT = 0.29000E 04-0.75019E 04 0.10000E 03 LB-IN

SHTZT        0.52182E 00
S BZZ        0.78282E 02
S AZZ        0.28937E 01
SHEZR       -0.25786E 00
SHEZT       -0.57402E 01
S PRR       -0.43201E 02
S PTT        0.49775E 03


THETA =  210.00   DEGREES
TRANSFORMED FORCE  =-0.39069E 03 0.11009E 03 0.10000E 03 LB
TRANSFORMED MOMENT =-0.12390E 04-0.79460E 04 0.10000E 03 LB-IN

SHTZT        0.52182E 00
S BZZ        0.82927E 02
S AZZ        0.28937E 01
SHEZR       -0.25609E 00
SHEZT        0.63195E 01
S PRR       -0.43201E 02
S PTT        0.49775E 03
```

```
RADIAL DISTANCE OF POINTS =      5.50000 INCHES


LOADS APPLIED TO THE TIP

INTERNAL PRESSURE   =       100.00 PSI
APPLIED FORCE       =       100.00        100.00        100.00 LB
APPLIED MOMENT      =       100.00        100.00        100.00 LB-IN


DISTANCE FROM THE TIP TO THE CROSS SECTION      60.00 INCHES


LOADS ACTING ON THE CROSS SECTION
INTERNAL PRESSURE   =       100.00 PSI
APPLIED FORCE       =       686.79        100.00        100.00 LB
APPLIED MOMENT      =     -5900.00      23703.59        100.00 LB-IN
```

```
THETA =      0.0      DEGREES
TRANSFORMED FORCE   = 0.68679E 03 0.10000E 03 0.10000E 03 LB
TRANSFORMED MOMENT =-0.59000E 04 0.23704E 05 0.10000E 03 LB-IN

SHTZT         0.52182E 00
S RZZ        -0.24738E 03
S AZZ         0.28937E 01
SHEZR         0.45018E 00
SHEZT         0.57402E 01
S PRR        -0.43201E 02
S PTT         0.49775E 03


THETA =     30.00     DEGREES
TRANSFORMED FORCE   = 0.64477E 03-0.25679E 03 0.10000E 03 LB
TRANSFORMED MOMENT = 0.67422E 04 0.23478E 05 0.10000E 03 LB-IN

SHTZT         0.52182E 00
S RZZ        -0.24502E 03
S AZZ         0.28937E 01
SHEZR         0.42264E 00
SHEZT        -0.14740E 02
S PRR        -0.43201E 02
S PTT         0.49775E 03


THETA =     60.00     DEGREES
TRANSFORMED FORCE   = 0.43000E 03-0.54477E 03 0.10000E 03 LB
TRANSFORMED MOMENT = 0.17578E 05 0.16961E 05 0.10000E 03 LB-IN

SHTZT         0.52182E 00
S RZZ        -0.17702E 03
S AZZ         0.28937E 01
SHEZR         0.23186E 00
SHEZT        -0.31271E 02
S PRR        -0.43201E 02
S PTT         0.49775E 03


THETA =     90.00     DEGREES
TRANSFORMED FORCE   = 0.10000E 03-0.68679E 03 0.10000E 03 LB
TRANSFORMED MOMENT = 0.23704E 05 0.59000E 04 0.10000E 03 LB-IN

SHTZT         0.52182E 00
S RZZ        -0.61575E 02
S AZZ         0.28937E 01
SHEZR         0.65549E-01
SHEZT        -0.39423E 02
S PRR        -0.43201E 02
S PTT         0.49775E 03
```

```
THETA =   120.00     DEGREES
TRANSFORMED FORCE   =-0.25679E 03-0.64477E 03 0.10000E 03 LB
TRANSFORMED MOMENT = 0.23478E 05-0.67422E 04 0.10000E 03 LB-IN

SHTZT         0.52182E 00
S BZZ         0.70364E 02
S AZZ         0.28937E 01
SHFZR        -0.16832E 00
SHFZT        -0.37011E 02
S PRR        -0.43201E 02
S PTT         0.49775E 03


THETA =   150.00     DEGREES
TRANSFORMED FORCE   =-0.54477E 03-0.43000E 03 0.10000E 03 LB
TRANSFORMED MOMENT = 0.16961E 05-0.17578E 05 0.10000E 03 LB-IN

SHTZT         0.52182E 00
S BZZ         0.18345E 03
S AZZ         0.28937E 01
SHFZR        -0.35709E 00
SHFZT        -0.24682E 02
S PRR        -0.43201E 02
S PTT         0.49775E 03


THETA =   180.00     DEGREES
TRANSFORMED FORCE   =-0.68679E 03-0.10000E 03 0.10000E 03 LB
TRANSFORMED MOMENT = 0.59000E 04-0.23704E 05 0.10000E 03 LB-IN

SHTZT         0.52182E 00
S BZZ         0.24738E 03
S AZZ         0.28937E 01
SHFZR        -0.45018E 00
SHFZT        -0.57402E 01
S PRR        -0.43201E 02
S PTT         0.49775E 03


THETA =   210.00     DEGREES
TRANSFORMED FORCE   =-0.64477E 03 0.25679E 03 0.10000E 03 LB
TRANSFORMED MOMENT =-0.67422E 04-0.23478E 05 0.10000E 03 LB-IN

SHTZT         0.52182E 00
S BZZ         0.24502E 03
S AZZ         0.28937E 01
SHFZR        -0.42264E 00
SHFZT         0.14740E 02
S PRR        -0.43201E 02
S PTT         0.49775E 03
```

```
THETA =  240.00    DEGREES
TRANSFORMED FORCE   =-0.43000E 03 0.54477E 03 0.10000E 03 LB
TRANSFORMED MOMENT =-0.17578E 05-0.16961E 05 0.10000E 03 LB-IN

SHTZT          0.52182E 00
S BZZ          0.17702E 03
S AZZ          0.28937E 01
SHFZR         -0.28186E 00
SHFZT          0.31271E 02
S PRR         -0.43201E 02
S PTT          0.49775E 03


THETA =  270.00    DEGREES
TRANSFORMED FORCE   =-0.10000E 03 0.68679E 03 0.10000E 03 LB
TRANSFORMED MOMENT =-0.23704E 05-0.59000E 04 0.10000E 03 LB-IN

SHTZT          0.52182E 00
S BZZ          0.61575E 02
S AZZ          0.28937E 01
SHFZR         -0.65549E-01
SHFZT          0.39423E 02
S PRR         -0.43201E 02
S PTT          0.49775E 03


THETA =  300.00    DEGREES
TRANSFORMED FORCE   = 0.25679E 03 0.64477E 03 0.10000E 03 LB
TRANSFORMED MOMENT =-0.23478E 05 0.67422E 04 0.10000E 03 LB-IN

SHTZT          0.52182E 00
S BZZ         -0.70364E 02
S AZZ          0.28937E 01
SHFZR          0.16832E 00
SHFZT          0.37011E 02
S PRR         -0.43201E 02
S PTT          0.49775E 03


THETA =  330.00    DEGREES
TRANSFORMED FORCE   = 0.54477E 03 0.43000E 03 0.10000E 03 LB
TRANSFORMED MOMENT =-0.16961E 05 0.17578E 05 0.10000E 03 LB-IN

SHTZT          0.52182E 00
S BZZ         -0.18345E 03
S AZZ          0.28937E 01
SHFZR          0.35709E 00
SHFZT          0.24682E 02
S PRR         -0.43201E 02
S PTT          0.49775E 03
```

APPENDIX B

DIGITAL COMPUTER PROGRAM FOR SECTION 2 AND NUMERICAL RESULTS

The programs presented herein provide a method for applying the theory developed in Section 2 of this thesis. Actual situations can be handled by subroutines ZULIA, GUAYRA, CUMANA and DSIMQ (DSIMQ is presented in Appendix D). Simulated situations require in addition subroutines CANTIL presented in Appendix A, and TIUNA and BLANCA presented in this Appendix. The last of the subroutines mentioned is an adaptation of a subroutine taken from reference 7 of this thesis.

ZULIA is used to specify the required information, such as material properties, number of Fourier coefficients to be computed and description of the arrangement of strain gage elements and their transverse sensitivity factor. Enough self explanatory comment statements have been included which specify the introduction of the information. Print-out statements present the information received for processing. Once the information is properly arranged, subroutine GUAYRA is used to make the required computations.

The sequence in GUAYRA follows closely the theoretical development of the method. It has sufficient comment statements separating blocks of computer processing instructions as to follow the theoretical procedure. Print-out statements present the computed Fourier coefficients.

CUMANA is used by GUAYRA for auxiliary computations.

Use of the subroutines is made by a very brief main program TERESITA. This program merely dimensions the various subroutines and turns control over to subroutine ZULIA. The card arrangement of the source deck is as shown in Fig. B.1.

Some sample results of the application of the program as specified at the end of Section 2, follow the card listings of the programs.

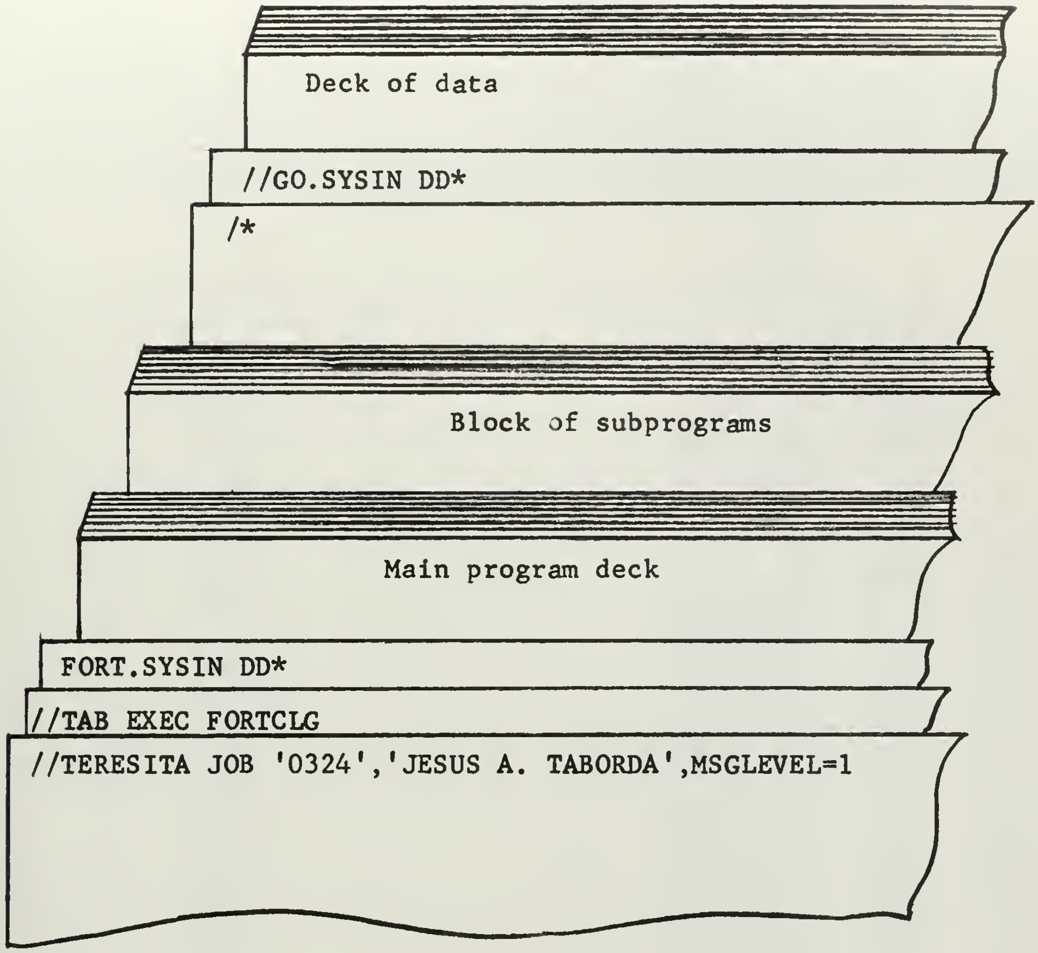

Deck of data
//GO.SYSIN DD*
/*
Block of subprograms
Main program deck
FORT.SYSIN DD*
//TAB EXEC FORTCLG
//TERESITA JOB '0324','JESUS A. TABORDA',MSGLEVEL=1

Fig. B.1

```
//TERESITA  JOB  '0324','TABORDA, JESUS A.',MSGLEVEL=1
//TAB  EXEC  FORTCLG
//FORT   EXEC  PGM=IFYFORT                                              00000010
      DIMENSION  Z1(36), Z2(36), Z3(37), Z4(37), Z5(36,36), Z6(36,36)    ZULIA
      DIMENSION  STRNEX(36), FSET(36,36), HSET(36), A(36), B(36),       GUAYRA
     1 C(36), ST(360), SL(360), SH(360), STA(10), STB(10), SLA(10),     GUAYRA
     2 SLB(10), SHA(10), SHB(10)                                        GUAYRA
      DIMENSION AF1(3), AXM1(3), AF(3), AXM(3), F(3), XM(3), FWGHT(3),  CANTIL
     1 XL1(5), XL2(3), ER(3), ET(3), EZ(3), R(3), ALL1(3,360,5),        CANTIL
     2 SHTZT(3),SBZZ(3),SAZZ(3),SHFZR(3),SHFZT(3),SPRR(3),SPTT(3)       CANTIL
      DIMENSION  F(3,3)                                                 TRANSF
      DIMENSION  A1(3),A2(3),A3(3),A4(3),F3(3),F4(3),F5(3),F6(3),      SCRATCH
     1 XM3(3),XM4(3),XM5(3),XM6(3),B1(3),B2(3),B3(3),B4(3),B5(3),B6(3), SCRATCH
     2 C1(36,36),C2(36,36),C3(36,36),C4(36,36), C5(36), C6(36)         SCRATCH
C
C
      CALL ZULIA
C
C
      END
```

```
      SUBROUTINE ZULIA
C
C
      DIMENSION T(36),P(36),R(36,36),W(36),ALL1(3,360,5),
     1 STRNEX(36),         P1(37), T1(37),ZZ(36), NBAD(36)
C
C
C  SPECIFY NUMBER OF FOURIER COEFFICIENTS NCOEFF, NUMBER OF GAGE
C  ELEMENTS NGAGES, TRANSVERSE SENSITIVITY FACTOR TRANSV, AND COR-
C  RESPONDING ANGULAR POSITION IN THE CROSS SECTION (CONTAINED IN THE
C  ARRAY T1) AND ANGULAR ORIENTATION FROM TANGENTIAL AXIS (CONTAINED
C  IN ARRAY P1).
C
C
      NCOEFF = 5
      NGAGES = 36
      TRANSV = 0.01
      TRANS1 = TRANSV*100.0
 5000 K = 0
      DO 5001  I = 1, 36, 3
      P1(I   ) = 0.0
      P1(I+1) = 60.0
      P1(I+2) = 120.0
      T1(I   ) = K*30
      T1(I+1) = T1(I)
      T1(I+2) = T1(I)
 5001 K = K + 1
C
C
C  SET ANGLE P1(I) OF GAGE ELEMENTS FUNCTIONING IMPROPERLY TO 1.0E6
C  AND ELIMINATE THOSE. NUMBER OF EACH OF THE ELIMINATED ELEMENTS WILL
C  BE CONTAINED IN ARRAY NBAD FOR PRINT-OUT PURPOSES. ANGULAR POSITION
C  AND ORIENTATION OF THE REMAINING K ACTIVE ELEMENTS WILL BE CONTAINED
C  IN ARRAYS T AND P RESPECTIVELY.
C
C
      P1(12) = 1.0E6
      P1(22) = 1.0E6
      P1(24) = 1.0E6
      P1(25) = 1.0E6
      P1(33) = 1.0E6
   20 K = 0
      L = 0
      DO 3   I = 1, NGAGES
      IF( P1(I)  .GE.  1.0E6 ) GO TO 34
   33 K = K + 1
      P(K) = P1(I)
      T(K) = T1(I)
```

```
      GC TO 3
   34 L = L + 1
      NBAC(L) = I
    3 CONTINUE
C
C
C  SPECIFY MATERIAL PRCPERTIES: YOUNG'S MODULUS OF ELASTICITY XE, SHEAR
C  MODULUS OF ELASTICITY G, POISSON'S RATIO XNU.
C
C   IF THE MATHEMATICAL MODEL OF A PIPE IS USED, OUTPUTS ARGUMENTS OF
C   SUBROUTINE CANTIL WILL DO IT.
C
C
      CALL        CANTIL(RO,RI,XE,G,XNU,SPECW,D,XL1,NPOINT,AREA,ALL1)
C
C
C  SPECIFY READINGS OF THE GAGE ELEMENTS, TO BE CONTAINED IN ARRAY
C  STRNEX.
C
C   THEORETICAL READINGS CAN BE OBTAINED FROM THE OUTPUT  OF SUBROUTINE
C   TIUNA. THIS USES AS INFORMATION THE MATERIAL PROPERTIES AND ANGULAR
C   ORIENTATION OF EACH ELEMENT, AND THE STRESS COMPONENTS AT EACH
C   ELEMENT CENTER. THIS IS OBTAINED FROM THE OUTPUT  ALL1 OF CANTIL,
C   REQUIERING THE ANGULAR POSITION IN THE CROSS SECTION AND THE CROSS
C   SECTION NUMBER TO IDENTIFY THE RIGHT STRESSES.
C
C
      NSECT = 1
      CALL TIUNA(XE,G,XNU,NSECT,ALL1,K,T,P,ZZ,TRANSV)
C
C
C   RANDOM ERRORS CAN BE ADDED TO THE THEORETICAL READINGS OF THE
C   GAGES,  THE OUTPUT ZZ OF TIUNA, BY USING SUBROUTINE BLANCA.
C   SPECIFY THE MULTIPLIER ALT TO OBTAIN (ALT)*(10%) MAXIMUN RANDOM
C   ERROR ADDED.
C
C
      ALT = 0.3
      CALL BLANCA(STRNEX,ZZ,K,ALT)
C
C
C  PRINT-OUT OF ALL THE INFORMATION OBTAINED UP TO NOW.
C
C
      WRITE(6, 500)
  500 FORMAT(1H1)
      WRITE(6, 11)  NCOEFF
   11 FORMAT(7(/),15X,'EXPANSION WITH',I3,'  FOURIER COEFFICIENTS'//)
```

```
      SUBROUTINE ZULIA
C
C
      DIMENSION T(36),P(36),R(36,36),W(36),ALL1(3,360,5),
     1 STRNFX(36),         P1(37), T1(37),ZZ(36), NBAD(36)
C
C
C   SPECIFY NUMBER OF FOURIER COEFFICIENTS NCOEFF, NUMBER OF GAGE
C   ELEMENTS NGAGES, TRANSVERSE SENSITIVITY FACTOR TRANSV, AND COR-
C   RESPONDING ANGULAR POSITION IN THE CROSS SECTION (CONTAINED IN THE
C   ARRAY T1) AND ANGULAR ORIENTATION FROM TANGENTIAL AXIS (CONTAINED
C   IN ARRAY P1).
C
C
      NCOEFF = 5
      NGAGES = 36
      TRANSV = 0.01
      TRANS1 = TRANSV*100.0
 5000 K = 0
      DO 5001  I = 1, 36, 3
      P1(I  ) = 0.0
      P1(I+1) = 60.0
      P1(I+2) = 120.0
      T1(I  ) = K*30
      T1(I+1) = T1(I)
      T1(I+2) = T1(I)
 5001 K = K + 1
C
C
C   SET ANGLE P1(I) OF GAGE ELEMENTS FUNCTIONING IMPROPERLY TO 1.0E6
C   AND ELIMINATE THOSE. NUMBER OF EACH OF THE ELIMINATED ELEMENTS WILL
C   BE CONTAINED IN ARRAY NBAD FOR PRINT-OUT PURPOSES. ANGULAR POSITION
C   AND ORIENTATION OF THE REMAINING K ACTIVE ELEMENTS WILL BE CONTAINED
C   IN ARRAYS T AND P RESPECTIVELY.
C
C
      P1(12) = 1.0E6
      P1(22) = 1.0E6
      P1(24) = 1.0E6
      P1(25) = 1.0E6
      P1(33) = 1.0E6
   20 K = 0
      L = 0
      DO 3   I = 1, NGAGES
      IF( P1(I)  .GE.  1.0E6 ) GO TO 34
   33 K = K + 1
      P(K) = P1(I)
      T(K) = T1(I)
```

```
      GC TO 3
   34 L = L + 1
      NBAC(L) = I
    3 CONTINUE
C
C
C  SPECIFY MATERIAL PRCPERTIES: YOUNG'S MODULUS OF ELASTICITY XE, SHEAR
C  MODULUS OF ELASTICITY G, POISSON'S RATIO XNU.
C
C   IF THE MATHEMATICAL MODEL OF A PIPE IS USED, OUTPUTS ARGUMENTS OF
C   SUBROUTINE CANTIL WILL DO IT.
C
C
      CALL        CANTIL(RO,RI,XE,G,XNU,SPECW,D,XL1,NPOINT,AREA,ALL1)
C
C
C  SPECIFY READINGS OF THE GAGE ELEMENTS, TO BE CONTAINED IN ARRAY
C  STRNEX.
C
C   THEORETICAL READINGS CAN BE OBTAINED FROM THE OUTPUT  OF SUBROUTINE
C   TIUNA. THIS USES AS INFORMATION THE MATERIAL PROPERTIES AND ANGULAR
C   ORIENTATION OF EACH ELEMENT, AND THE STRESS COMPONENTS AT EACH
C   ELEMENT CENTER. THIS IS OBTAINED FROM THE OUTPUT  ALL1 OF CANTIL,
C   REQUIERING THE ANGULAR POSITION IN THE CROSS SECTION AND THE CROSS
C   SECTION NUMBER TO IDENTIFY THE RIGHT STRESSES.
C
C
      NSECT = 1
      CALL TIUNA(XE,G,XNU,NSECT,ALL1,K,T,P,ZZ,TRANSV)
C
C
C   RANDOM ERRORS CAN BE ADDED TO THE THEORETICAL READINGS OF THE
C   GAGES,  THE OUTPUT ZZ OF TIUNA, BY USING SUBROUTINE BLANCA.
C   SPECIFY THE MULTIPLIER ALT TO OBTAIN (ALT)*(10?) MAXIMUN RANDOM
C   ERROR ADDED.
C
C
      ALT = 0.3
      CALL BLANCA(STRNEX,ZZ,K,ALT)
C
C
C  PRINT-OUT OF ALL THE INFORMATION OBTAINED UP TO NOW.
C
C
      WRITE(6, 500)
  500 FORMAT(1H1)
      WRITE(6, 11)  NCOEFF
   11 FORMAT(7(/),15X,'EXPANSION WITH',I3,'  FOURIER COEFFICIENTS'//)
```

```
      WRITE(6, 30)  XE, G, XNU, NGAGES, TRANS1, K                        ZULIA097
30    FORMAT(15X,'MODULUS OF ELASTICITY',E13.5,'PSI' /                   ZULIA098
     1        15X,'SHEAR MODULUS OF ELASTICITY',E13.5,' PSI' /           ZULIA099
     2        15X,'POISSON RATIO',E13.5  ///                             ZULIA100
     3        15X,'NUMBER OF GAGES', I4 /                                ZULIA101
     4 15X,'TRANSVERSE SENSITIVITY FACTOR OF THE GAGES = ', F6.2,' %' /  ZULIA102
     5        15X,'NUMBER OF GAGES FUNCTIONING PROPERLY', I4   )         ZULIA103
      IF(   L   .EQ.   0 )   GO TO 71                                    ZULIA104
72    WRITE(6, 73)   ( NBAD(I),  I = 1, L)                               ZULIA105
73    FORMAT(15X,'GAGES FUNCTIONING IMPROPERLY',3X, 8(I3,',') /          ZULIA106
     1   ( 38X, 8(I3,',')   )   )                                        ZULIA107
      GO TO 82                                                           ZULIA108
71    WRITE(6, 74)                                                       ZULIA109
74    FORMAT(15X,'GAGES FUNCTIONING IMPROPERLY ... NONE' )               ZULIA110
82    WRITE(6, 83)   ( T(N),   N = 1, K )                                ZULIA111
83    FORMAT(//15X,'ANGULAR POSITION OF THE GAGE IN THE CROSS SECTION,'ZULIA112
     1 ' READ ROW WISE' // (15X, 6E15.5) )                               ZULIA113
      WRITE(6, 84)   ( P(N),   N = 1, K )                                ZULIA114
84    FORMAT(//15X,'ANGULAR ORIENTATION OF THE GAGES, READ ROW WISE' //ZULIA115
     1      ( 15X, 6E15.5 )   )                                          ZULIA116
      WRITE(6, 85)   (STRNEX(N), N = 1, K )                              ZULIA117
85    FORMAT(// 15X, 'READINGS OF THE GAGE ELEMENTS, READ ROW WISE' //   ZULIA118
     1      (15X, 6E15.5) )                                              ZULIA119
C                                                                        ZULIA120
C                                                                        ZULIA121
C   DETERMINATION OF THE FOURIER COEFFICIENTS. SUBROUTINE GUAYRA WILL    ZULIA122
C   APPLY THE MATHEMATICAL METHOD FOR THIS. THE NUMBER J = NCOEFF*3      ZULIA123
C   = THE TOTAL NUMBER OF COEFFICIENTS TO BE DETERMINED, IS NEEDED FOR   ZULIA124
C   DIMENSIONING ARRAYS R AND W. NSECT AND ALL1 CAN BE USED FOR COMPAR-  ZULIA125
C   ISONS BETWEEN THE ESTIMATED STRESS DISTRIBUTIONS AND THE THEORETICAL ZULIA126
C   ONES TAKEN FROM CANTIL.                                              ZULIA127
C                                                                        ZULIA128
C                                                                        ZULIA129
      J = 3*NCOEFF                                                       ZULIA130
      CALL GUAYRA(NCOEFF,K,T,P,STRNEX,XE,G,XNU,J,R,W,NSECT,ALL1,TRANSV)ZULIA131
      RETURN                                                             ZULIA132
      END                                                                ZULIA133
```

```
      SUBROUTINE GUAYRA(NCOEFF, NGAGES,THETA,PHI,STRNEX,XE,G,XNU,
     1 JJ,R,W,NSECT,ALL1,TRANSV)
C
C
C  DETERMINES FOURIER COEFFICIENTS FOR THE DISTRIBUTIONS OF TANGENTIAL,
C  LONGITUDINAL AND SHEAR STRESSES. ALL ARGUMENTS ARE IMPUTS.
C
C
C     NCOEFF = NUMBER OF FOURIER COEFFICIENTS FOR EACH STRESS DISTRIBUT-
C           ION.
C     NGAGES = NUMBER OF ACTIVE GAGE ELEMENTS.
C     THETA = ARRAY CONTAINING THE ANGULAR POSITION OF THE ELEMENTS
C           AROUND THE CROSS SECTION.
C     PHI = ARRAY CONTAINING THE ANGULAR ORIENTATION WITH RESPECT TO THE
C           TANGENTIAL AXIS, OF THE ELEMENTS.
C     STRNEX = ARRAY CONTAINING THE READINGS OF THE ELEMENTS.
C     XE = YOUNG'S MODULUS OF ELASTICITY.
C     G = SHEAR MODULUS OF ELASTICITY.
C     XNU = POISSON'S RATIO.
C     JJ = 3*NCOEFF = TOTAL NUMBER OF COEFFICIENTS TO BE DETERMINED,
C           SPECIFIED IN CALLING PROGRAM TO DIMENSION R AND W.
C     NSECT AND ALL1 CAN BE USED TO COMPARE THE ESTIMATED STRESS DIS-
C           TRIBUTIONS AND THE THEORETICAL ONES FROM SUBPROGRAM CANTIL.
C
C
      DIMENSION THETA(36), PHI(36), ALL1(3,360,5),STRNEX(36), A(36),
     1 B(36), C(36), H(36), F(36,36), ST(360),SL(360),SH(360),STA(10),
     2 STB(10),SLA(10),SLB(10),SHA(10),SHB(10)
      DIMENSION R(JJ,JJ),W(JJ)
C
C
C  DETERMINE COEFFICIENTS A, B AND C.
C
C
      CALL CUMANA(XE, G, XNU,NGAGES,PHI,A, B, C, TRANSV)
      WRITE (6,88)
   88 FORMAT( 1H1 )
      WRITE(6, 33)  ( A(N),  N = 1, NGAGES )
   33 FORMAT(7(/),15X,'COEFFICIENTS A, READ ROW WISE'//(15X,6F15.5))
      WRITE(6, 34)  ( B(N),  N = 1, NGAGES )
   34 FORMAT( // 15X,'COEFFICIENTS B, READ ROW WISE'//(15X,6F15.5))
      WRITE(6, 35)  ( C(N),  N = 1, NGAGES )
   35 FORMAT( // 15X,'COEFFICIENTS C, READ ROW WISE'//(15X,6F15.5))
C
C
C  FORM SET OF SIMULTANEOUS EQUATIONS TO SOLVE FOR NSMLX6 FOURIER COEF-
C  FICIENTS.  IN MATRIX NOTATION: (F)X(COEFF'S) = (H).
C
```

```
C                                                         GUAYR048
      NSML = NCOEFF/2 + 1                                 GUAYR049
      NSMLX6 = NSML*6                                     GUAYR050
      PI2 = 3.14159265/180.0                              GUAYR051
C                                                         GUAYR052
C     DETERMINE CONSTANTS H'S.                            GUAYR053
C                                                         GUAYR054
      DO 3  L = 1, NSMLX6                                 GUAYR055
    3 H(L) = 0.0                                          GUAYR056
      K = 0                                               GUAYR057
      DO 4  L = 1, NSMLX6, 6                              GUAYR058
      LA = L                                              GUAYR059
      L6 = L + 5                                          GUAYR060
      AK = K                                              GUAYR061
      K = K + 1                                           GUAYR062
      DO 4  I = 1, NGAGES                                 GUAYR063
      P1 = THETA(I)*PI2                                   GUAYR064
      C1 = COS( AK*P1 )                                   GUAYR065
      S1 = SIN( AK*P1 )                                   GUAYR066
      H(L  ) = H(L  ) + STRNEX(I)*A(I)*C1                 GUAYR067
      H(L+1) = H(L+1) + STRNEX(I)*A(I)*S1                 GUAYR068
      H(L+2) = H(L+2) + STRNEX(I)*B(I)*C1                 GUAYR069
      H(L+3) = H(L+3) + STRNEX(I)*B(I)*S1                 GUAYR070
      H(L+4) = H(L+4) + STRNEX(I)*C(I)*C1                 GUAYR071
      H(L+5) = H(L+5) + STRNEX(I)*C(I)*S1                 GUAYR072
    4 CONTINUE                                            GUAYR073
C                                                         GUAYR074
C     DETERMINE COEFFICIENTS F'S.                         GUAYR075
C                                                         GUAYR076
      DO 1  L = 1, NSMLX6                                 GUAYR077
      DO 1  M = 1, NSMLX6                                 GUAYR078
    1 F(L,M) = 0.0                                        GUAYR079
      K = 0                                               GUAYR080
      DO 2  L = 1, NSMLX6, 6                              GUAYR081
      J = 0                                               GUAYR082
      AK = K                                              GUAYR083
      K = K + 1                                           GUAYR084
      LA = L                                              GUAYR085
      L6 = L + 5                                          GUAYR086
      DO 2  M = 1, NSMLX6, 6                              GUAYR087
      AJ = J                                              GUAYR088
      J = J + 1                                           GUAYR089
      MA = M                                              GUAYR090
      M6 = M + 5                                          GUAYR091
      DO 2  I = 1, NGAGES                                 GUAYR092
      AA = A(I)*A(I)                                      GUAYR093
      AB = A(I)*B(I)                                      GUAYR094
      AC = A(I)*C(I)                                      GUAYR095
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```
      BB = B(I)*B(I)                                                   GUAYR096
      BC = B(I)*C(I)                                                   GUAYR097
      CC = C(I)*C(I)                                                   GUAYR098
      P1 = THETA(I)*PI2                                                GUAYR099
      C1 = COS( AK*P1 )*COS( AJ*P1 )                                   GUAYR100
      C2 = COS( AK*P1 )*SIN( AJ*P1 )                                   GUAYR101
      S1 = SIN( AK*P1 )*COS( AJ*P1 )                                   GUAYR102
      S2 = SIN( AK*P1 )*SIN( AJ*P1 )                                   GUAYR103
      F(L  , M  ) = F(L  , M  ) + AA*C1                                GUAYR104
      F(L  , M+1) = F(L  , M+1) + AA*C2                                GUAYR105
      F(L  , M+2) = F(L  , M+2) + AB*C1                                GUAYR106
      F(L  , M+3) = F(L  , M+3) + AB*C2                                GUAYR107
      F(L  , M+4) = F(L  , M+4) + AC*C1                                GUAYR108
      F(L  , M+5) = F(L  , M+5) + AC*C2                                GUAYR109
      F(L+1, M  ) = F(L+1, M  ) + AA*S1                                GUAYR110
      F(L+1, M+1) = F(L+1, M+1) + AA*S2                                GUAYR111
      F(L+1, M+2) = F(L+1, M+2) + AB*S1                                GUAYR112
      F(L+1, M+3) = F(L+1, M+3) + AB*S2                                GUAYR113
      F(L+1, M+4) = F(L+1, M+4) + AC*S1                                GUAYR114
      F(L+1, M+5) = F(L+1, M+5) + AC*S2                                GUAYR115
      F(L+2, M  ) = F(L+2, M  ) + AB*C1                                GUAYR116
      F(L+2, M+1) = F(L+2, M+1) + AB*C2                                GUAYR117
      F(L+2, M+2) = F(L+2, M+2) + BB*C1                                GUAYR118
      F(L+2, M+3) = F(L+2, M+3) + BB*C2                                GUAYR119
      F(L+2, M+4) = F(L+2, M+4) + BC*C1                                GUAYR120
      F(L+2, M+5) = F(L+2, M+5) + BC*C2                                GUAYR121
      F(L+3, M  ) = F(L+3, M  ) + AB*S1                                GUAYR122
      F(L+3, M+1) = F(L+3, M+1) + AB*S2                                GUAYR123
      F(L+3, M+2) = F(L+3, M+2) + BB*S1                                GUAYR124
      F(L+3, M+3) = F(L+3, M+3) + BB*S2                                GUAYR125
      F(L+3, M+4) = F(L+3, M+4) + BC*S1                                GUAYR126
      F(L+3, M+5) = F(L+3, M+5) + BC*S2                                GUAYR127
      F(L+4, M  ) = F(L+4, M  ) + AC*C1                                GUAYR128
      F(L+4, M+1) = F(L+4, M+1) + AC*C2                                GUAYR129
      F(L+4, M+2) = F(L+4, M+2) + BC*C1                                GUAYR130
      F(L+4, M+3) = F(L+4, M+3) + BC*C2                                GUAYR131
      F(L+4, M+4) = F(L+4, M+4) + CC*C1                                GUAYR132
      F(L+4, M+5) = F(L+4, M+5) + CC*C2                                GUAYR133
      F(L+5, M  ) = F(L+5, M  ) + AC*S1                                GUAYR134
      F(L+5, M+1) = F(L+5, M+1) + AC*S2                                GUAYR135
      F(L+5, M+2) = F(L+5, M+2) + BC*S1                                GUAYR136
      F(L+5, M+3) = F(L+5, M+3) + BC*S2                                GUAYR137
      F(L+5, M+4) = F(L+5, M+4) + CC*S1                                GUAYR138
      F(L+5, M+5) = F(L+5, M+5) + CC*S2                                GUAYR139
    2 CONTINUE                                                         GUAYR140
C                                                                      GUAYR141
C                                                                      GUAYR142
C  ELIMINATE ROWS AND COLUMNS OF ALL-ZERO ELEMENTS IN MATRIX F, COR-   GUAYR143
```

```
C     RESPONDING TO THE FOURIER COEFFICIENTS OF THE TERMS CONTAINING       GUAYR144
C     SIN(0), SO TO FORM A NONSINGULAR SET OF EQUATIONS.  ELIMINATE COR-   GUAYR145
C     RESPONDING ELEMENTS IN CONSTANT MATRIX H.  THE MATRIX EQUATION IS    GUAYR146
C     CONVERTED THEN TO (R)X(COEFF'S) = (W).                               GUAYR147
C                                                                          GUAYR148
C                                                                          GUAYR149
          W(1) = H(1)                                                      GUAYR150
          R(1,1) = F(1,1)                                                  GUAYR151
          W(2) = H(3)                                                      GUAYR152
          W(3) = H(5)                                                      GUAYR153
          R(1,2) = F(1,3)                                                  GUAYR154
          R(1,3) = F(1,5)                                                  GUAYR155
          R(2,1) = F(3,1)                                                  GUAYR156
          R(2,2) = F(3,3)                                                  GUAYR157
          R(2,3) = F(3,5)                                                  GUAYR158
          R(3,1) = F(5,1)                                                  GUAYR159
          R(3,2) = F(5,3)                                                  GUAYR160
          R(3,3) = F(5,5)                                                  GUAYR161
          DO 50  M = 4, JJ                                                 GUAYR162
          W(M) = H(M+3)                                                    GUAYR163
          R(1,M) = F(1, M+3)                                               GUAYR164
          R(2,M) = F(3, M+3)                                               GUAYR165
          R(3,M) = F(5, M+3)                                               GUAYR166
          DO 50  L = 1, 3                                                  GUAYR167
    50    R(M,L) = R(L,M)                                                  GUAYR168
          DO 51  L = 4, JJ                                                 GUAYR169
          DO 51  M = 4, JJ                                                 GUAYR170
    51    R(L,M) = F(L+3, M+3)                                             GUAYR171
C                                                                          GUAYR172
C                                                                          GUAYR173
C     SOLVE THE SET OF SIMULTANEOUS EQUATIONS TO DETERMINE JJ FOURIER     GUAYR174
C     COEFFICIENTS.                                                        GUAYR175
C                                                                          GUAYR176
C                                                                          GUAYR177
          CALL DSIMQ(R,W,JJ,KS)                                            GUAYR178
          WRITE(6, 38)                                                     GUAYR179
          WRITE(6, 12)  NCOEFF                                             GUAYR180
    12    FORMAT(7(/),15X,'EXPANSION WITH',I3,'  FOURIER COEFFICIENTS' )   GUAYR181
          WRITE (6, 100)  KS                                               GUAYR182
   100    FORMAT( //  15X,'KS =',I2,'     KS IS AN INDEX INDICATING TYPE ', GUAYR183
         1 'OF SOLUTION: 0 FOR NORMAL, 1 FOR SINGULAR' )                   GUAYR184
C                                                                          GUAYR185
C                                                                          GUAYR186
C     GROUP THE FOURIER COEFFICIENTS FOR THE TANGENTIAL STRESS IN THE      GUAYR187
C     ARRAY STA, CORRESPONDING TO THE TERM CONTAINIG COS(N THETA), AND IN  GUAYR188
C     THE ARRAY STB CORRESPONDINGLY FOR THE TERMS IN SIN(N THETA), FOR     GUAYR189
C     N = 1, 2, ...,(NCOEFF/2 + 1).                                        GUAYR190
C     SAME FOR LONGITUDINAL STRESS WITH SLA AND SLB, AND FOR SHEAR STRESS  GUAYR191
```

```
C    WITH SHA AND SHB.
C
C
         STA(1) = W(1)
         SLA(1) = W(2)
         SHA(1) = W(3)
         STB(1) = 0.0
         SLB(1) = 0.0
         SHB(1) = 0.0
         K = 4
         DO 8  N = 2, NSML
         STA(N) = W(K  )
         STB(N) = W(K+1)
         SLA(N) = W(K+2)
         SLB(N) = W(K+3)
         SHA(N) = W(K+4)
         SHB(N) = W(K+5)
         K = K + 6
    8    CONTINUE
C
C
C    PREPARE ORDERLY PRINT-OUT OF THE FOURIER COEFFICIENTS.
C
C
         WRITE(6, 20)  STA(1), SLA(1), SHA(1)
   20    FORMAT(//15X,'FOURIER COEFFICIENTS'//15X,8X,'CONSTANTS'/
     1   15X,'TANG.',E14.5 /15X,'LONG.',E14.5/15X,'SHEAR',F14.5 )
         IF( NCOEFF  .LT.  3 )   GO TO 600
         IF( NCOEFF  .EQ.  3 )  GO TO 3000
         IF( NCOEFF  .EQ.  5 )  GO TO 5000
         IF( NCOEFF  .EQ.  7 )  GO TO 7000
         IF( NCOEFF  .EQ.  9 )  GO TO 9000
         IF( NCOEFF  .EQ.  11 )  GO TO 9050
 3000    M = 1
         KS = 1
         I = 2
         LA = 2
         WRITE(6, 3001)  (K,K, K = M,KS), (STA(N), STB(N), N = I,LA),
     1       (SLA(N),SLB(N), N=I,LA), (SHA(N),SHB(N), N=I,LA)
 3001    FORMAT(//20X,  2X,'COS',I2,'(THETA)',2X,'SIN',I2,'(THETA)'  /
     1   15X,'TANG.',2F14.5/15X,'LONG.',2E14.5/15X,'SHEAR',2E14.5 // )
         GO TO 600
 5000    M = 1
         KS = 2
         I = 2
         LA = 3
         WRITE(6, 5001)  (K,K, K = M,KS), (STA(N), STB(N), N = I,LA),
     1       (SLA(N),SLB(N), N=I,LA), (SHA(N),SHB(N), N=I,LA)
```

```
 5001  FORMAT(//20X,2(2X,'COS',I2,'(THETA)',2X,'SIN',I2,'(THETA)') /        GUAYR240
     1 15X,'TANG.',4F14.5/15X,'LONG.',4F14.5/15X,'SHEAR',4F14.5 // )        GUAYR241
       GO TO 600                                                             GUAYR242
 7000  M = 1                                                                 GUAYR243
       KS = 3                                                                GUAYR244
       I = 2                                                                 GUAYR245
       LA = 4                                                                GUAYR246
       WRITE(6, 7001)  (K,K, K = M,KS), (STA(N), STB(N), N = I,LA),          GUAYR247
     1      (SLA(N),SLB(N), N=I,LA), (SHA(N),SHB(N), N=I,LA)                 GUAYR248
 7001  FORMAT(//20X,3(2X,'COS',I2,'(THETA)',2X,'SIN',I2,'(THETA)') /        GUAYR249
     1 15X,'TANG.',6E14.5/15X,'LONG.',6F14.5/15X,'SHEAR',6F14.5 // )        GUAYR250
       GO TO 600                                                             GUAYR251
 9000  M = 1                                                                 GUAYR252
       KS = 3                                                                GUAYR253
       I = 2                                                                 GUAYR254
       LA = 4                                                                GUAYR255
       WRITE(6, 7001)  (K,K, K = M,KS), (STA(N), STB(N), N = I,LA),          GUAYR256
     1      (SLA(N),SLB(N), N=I,LA), (SHA(N),SHB(N), N=I,LA)                 GUAYR257
       M = 4                                                                 GUAYR258
       KS = 4                                                                GUAYR259
       I = 5                                                                 GUAYR260
       LA = 5                                                                GUAYR261
       WRITE(6, 3001)  (K,K, K = M,KS), (STA(N), STB(N), N = I,LA),          GUAYR262
     1      (SLA(N),SLB(N), N=I,LA), (SHA(N),SHB(N), N=I,LA)                 GUAYR263
       GO TO 600                                                             GUAYR264
 9050  M = 1                                                                 GUAYR265
       KS = 3                                                                GUAYR266
       I = 2                                                                 GUAYR267
       LA = 4                                                                GUAYR268
       WRITE(6, 7001)  (K,K, K = M,KS), (STA(N), STB(N), N = I,LA),          GUAYR269
     1      (SLA(N),SLB(N), N=I,LA), (SHA(N),SHB(N), N=I,LA)                 GUAYR270
       M = 4                                                                 GUAYR271
       KS = 5                                                                GUAYR272
       I = 5                                                                 GUAYR273
       LA = 6                                                                GUAYR274
       WRITE(6, 5001)  (K,K, K = M,KS), (STA(N), STB(N), N = I,LA),          GUAYR275
     1      (SLA(N),SLB(N), N=I,LA), (SHA(N),SHB(N), N=I,LA)                 GUAYR276
  600  CONTINUE                                                              GUAYR277
C                                                                            GUAYR278
C                                                                            GUAYR279
C   COMPUTE RESULTANT STRESS COMPONENTS EVERY 10 DEGREES AROUND THE          GUAYR280
C   CROSS SECTION.                                                           GUAYR281
C                                                                            GUAYR282
C                                                                            GUAYR283
       DO 5  I = 1, 36                                                       GUAYR284
       ST(I) = 0.0                                                           GUAYR285
       SL(I) = 0.0                                                           GUAYR286
    5  SH(I) = 0.0                                                           GUAYR287
```

```
C                                                                       GUAYR288
      PI3 = 10.0*PI2                                                    GUAYR289
      DO 6  I = 1, 36                                                   GUAYR290
      AI = I - 1                                                        GUAYR291
      PI = AI*PI3                                                       GUAYR292
      DO 6  N = 1, NSML                                                 GUAYR293
      AN = N - 1                                                        GUAYR294
      C1 = COS( AN*PI )                                                 GUAYR295
      S1 = SIN( AN*PI )                                                 GUAYR296
      ST(I) = ST(I) + STA(N)*C1 + STB(N)*S1                             GUAYR297
      SL(I) = SL(I) + SLA(N)*C1 + SLB(N)*S1                             GUAYR298
    6 SH(I) = SH(I) + SHA(N)*C1 + SHB(N)*S1                             GUAYR299
C                                                                       GUAYR300
C                                                                       GUAYR301
C  PREPARE PRINT-OUT OF THE COMPUTED STRESSES AND THE CORRESPONDING     GUAYR302
C  THEORETICAL ONES CONTAINED IN ALL1, IDENTIFIED BY THE NUMBER OF      GUAYR303
C  THE CROSS SECTION NSECT.                                             GUAYR304
C                                                                       GUAYR305
C                                                                       GUAYR306
      K = 1                                                             GUAYR307
      WRITE(6, 88)                                                      GUAYR308
      DO 7  N = 1, 36                                                   GUAYR309
      L = 10*(N - 1)                                                    GUAYR310
      J = L + 1                                                         GUAYR311
      IF( K  .LT.  13 )  GO TO 956                                      GUAYR312
  954 K = 1                                                             GUAYR313
      WRITE(6, 88)                                                      GUAYR314
  956 WRITE(6, 11)  L,J,(ALL1(I,J,NSECT), I = 1,3),ST(N),SL(N),SH(N)    GUAYR315
   11 FORMAT(// 15X, 'THETA =', I4, ' DEGREES', 5X, 'POINT NO.', I4 /  GUAYR316
     1 15X, 'STRESSES', 9X, 'TANG.', 12X, 'LONG.', 12X, 'SHEAR' /       GUAYR317
     2    15X,'ACTUAL   ',3E17.5/15X,'COMPUTED',3E17.5)                 GUAYR318
    7 K = K + 1                                                         GUAYR319
      RETURN                                                            GUAYR320
      END                                                               GUAYR321
```

```
      SUBROUTINE  CUMANA( E, G, V, NPOINT, P, A, B, C, AK)                CUMAN001
C                                                                          CUMAN002
C  TO COMPUTE COEFFICIENTS A, B AND C TO BE USED IN PROGRAM GUAYRA.       CUMAN003
C                                                                          CUMAN004
      DIMENSION  P(36), A(36), B(36), C(36)                               CUMAN005
      PI2 = 3.14159265/180.0                                              CUMAN006
      DO 4  N = 1, NPOINT                                                 CUMAN007
      P1 = P(N)*PI2                                                       CUMAN008
      A(N) = ((1.0-AK*V)-(1.0-AK)*(1.0+V)*SIN(P1)**2)/(E*(1.0-AK**2))     CUMAN009
      B(N) = ((1.0-AK*V)-(1.0-AK)*(1.0+V)*COS(P1)**2)/(E*(1.0-AK**2))     CUMAN010
    4 C(N) = ((1.0-AK)*SIN(2.0*P1))/(2.0*G*(1.0-AK**2))                   CUMAN011
      RETURN                                                              CUMAN012
      END                                                                 CUMAN013
```

```
      SUBROUTINE TIUNA(E,G,V,K,AL,NBIG,T,P,S,AK)
C
C
C
C   TO COMPUTE THE THEORETICAL READINGS OF A SET OF NBIG STRAIN GAGE
C   ELEMENTS WITH TRANVERSE SENSITIVITY  AK.
C
C     ANGULAR POSITIONS OF THE ELEMENTS ARE CONTAINED IN THE ARRAY OF
C     ANGLES T.
C     ANGULAR ORIENTATION OF THE ELEMENTS WITH RESPECT TO THE TANGENTIAL
C     AXIS ARE CONTAINED IN THE ARRAY OF ANGLES P.
C     COMPONENTS OF THE STRESSES AT EACH POSITION ARE CONTAINED IN THE
C     ARRAY AL.  K IS THE NUMBER OF THE CROSS SECTION TO IDENTIFY THE
C     CORRECT STRESSES.
C     E IS YOUNG'S MODULUS OF ELASTICITY.
C     G IS THE SHEAR MODULUS OF ELASTICITY.
C     V IS POISSON'S RATIO.
C     S IS THE OUTPUT SET OF READINGS.
C
C
      DIMENSION AL(3,360,5),T(36), P(36), S(36)
      PI2 = 3.14159265/180.0
      DO 4  N = 1, NBIG
      J = T(N) + 1.0
      P1 = P(N)*PI2
      S1     = AL(1,J,K)
      S2     = AL(2,J,K)
      S3     = AL(3,J,K)
      A     = ((1.0-AK*V)-(1.0-AK)*(1.0+V)*SIN(P1)**2)/(E*(1.0-AK**2))
      B     = ((1.0-AK*V)-(1.0-AK)*(1.0+V)*COS(P1)**2)/(E*(1.0-AK**2))
      C     = ((1.0-AK)*SIN(2.0*P1))/(2.0*G*(1.0-AK**2))
      S(N) = A*S1 + B*S2 + C*S3
    4 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE BLANCA( CO,BE,N,ALT )                                  BLANC001
C                                                                       BLANC003
C  INTRODUCES RANDOM ERRORS IN THE ELEMENTS OF ONE DIMENSIONAL ARRAY.   BLANC004
C    CO IS THE ARRAY IMPUT AND BE IS THE OUTPUT.                        BLANC005
C    N IS THE NUMBER OF ELEMENTS.                                       BLANC006
C    ALT IS A MULTIPLIER TO PRODUCE PLUS OR MINUS (ALT)*(10%) MAXIMUN   BLANC007
C    ERROR.                                                             BLANC008
C                                                                       BLANC009
      DIMENSION  CO(36),  BE(36)                                        BLANC010
      RHO = 1                                                           BLANC011
      DO 5  J = 1, N                                                    BLANC012
      Q = J                                                             BLANC013
      RHO = RHO + 3.6327                                                BLANC014
      IF ( RHO - 9.999 ) 12, 11, 11                                     BLANC015
   11 RHO = RHO - 8.4153                                                BLANC016
   12 XX = RHO**( Q/10.0 + 3.1416 )                                     BLANC017
      KX = XX                                                           BLANC018
      AKX = KX                                                          BLANC019
      BKX = XX - AKX                                                    BLANC020
      CKX = 10.0*BKX                                                    BLANC021
      TT = BE(J)                                                        BLANC022
      PERC = 0.01*ALT                                                   BLANC023
      QQ = PERC*CKX*TT                                                  BLANC024
      KKX = CKX                                                         BLANC025
      DKKX = KKX                                                        BLANC026
      FKKX = DKKX/2.0                                                   BLANC027
      LKKX = FKKX                                                       BLANC028
      GKKX = LKKX                                                       BLANC029
      OKKX = FKKX - GKKX                                                BLANC030
   15 IF(OKKX-0.5)3,1,3                                                 BLANC031
    3 CO(J) = TT + QQ                                                   BLANC032
      GO TO 5                                                           BLANC033
    1 CO(J) = TT - QQ                                                   BLANC034
    5 CONTINUE                                                          BLANC035
      PERC = PERC*1000.0                                                BLANC036
      WRITE(6, 60)  PERC                                                BLANC037
   60 FORMAT(1H1//15X, 'ALTERATION OF THE STRAIN GAGE READINGS' //      BLANC038
     1 15X, 'MAXIMUN ERROR INTRODUCED', F6.1, ' %' /// 34X, 'ORIGINAL', BLANC039
     2 7X, 'ALTERED' / )                                                BLANC040
      WRITE(6, 63)  ( BE(J), CO(J), J = 1, N )                          BLANC041
   63 FORMAT( 26X, 2E15.5 )                                             BLANC043
      RETURN                                                            BLANC043
      END                                                               BLANC044
```

MODULUS OF ELASTICITY C.30000E 08PSI
SHEAR MODULUS OF ELASTICITY 0.11538E 08 PSI
POISSON RATIO 0.30C00E 00

NUMBER OF GAGES 36
TRANSVERSE SENSITIVITY FACTOR OF THE GAGES = 0 %
NUMBER OF GAGES FUNCTIONING PROPERLY 36
GAGES FUNCTIONING IMPROPERLY ... NONE

ANGULAR POSITION CF THE GAGE IN THE CROSS SECTION, READ ROW WISF

0.0	C.0	0.0	0.30000E 02	0.30000E 02	0.30000E 02
0.60000E 02	C.60000E 02	0.60000E 02	0.90000E 02	0.90000E 02	0.90000E 02
0.12000E 03	C.12000E 03	0.12000E 03	0.15000E 03	0.15000E 03	0.15000E 03
0.18000E 03	C.18000E 03	0.18000E 03	0.21000E 03	0.21000E 03	0.21000E 03
0.24000E 03	0.24000E 03	0.24000E 03	0.27000E 03	0.27000E 03	0.27000E 03
0.30000E 03	C.30000E 03	0.30000E 03	0.33000E 03	0.33000E 03	0.33000E 03

ANGULAR ORIENTATION OF THE GAGES, READ ROW WISE

0.0	C.60000E 02	0.12000E 03	0.0	0.60000E 02	0.12000E 03
0.0	C.60000E 02	0.12000E 03	0.0	0.60000E 02	0.12000E 03
0.0	C.60000E 02	0.12000E 03	0.0	0.60000E 02	0.12000E 03
0.0	0.60000E 02	0.12000E 03	0.0	0.60000E 02	0.12000E 03
0.0	C.60000E 02	0.12000E 03	0.0	0.60000E 02	0.12000E 03
0.0	C.60000E 02	0.12000E 03	0.0	0.60000E 02	0.12000E 03

READINGS OF THE GAGE ELEMENTS, READ ROW WISE. ERROR ADDED 0%

0.15134E-04	C.64178E-06	0.19479E-06	0.15127E-04	0.52988E-06	0.33917E-06
0.15118E-04	C.40066E-06	0.50589E-06	0.15111E-04	0.28876E-06	0.65028E-06
0.15107E-04	0.22415E-06	0.73364E-06	0.15107E-04	0.22415E-06	0.73364E-06
0.15111E-04	0.28876E-06	0.65028E-06	0.15118E-04	0.40066E-06	0.50589E-06
0.15127E-04	0.52988E-06	0.33917E-06	0.15134E-04	0.64178E-06	0.19479E-06
0.15138E-04	C.70639E-06	0.11143E-06	0.15138E-04	0.70639E-06	0.11143E-06

COEFFICIENTS A, READ ROW WISE

0.33333E-07	0.83336E-09	0.83333E-09	0.33333E-07	0.83336E-09	0.83333E-09
0.33333E-07	0.83336E-09	0.83333E-09	0.33333E-07	0.83336E-09	0.83333E-09
0.33333E-07	0.83336E-09	0.83333E-09	0.33333E-07	0.83336E-09	0.83333E-09
0.33333E-07	0.83336E-09	0.83333E-09	0.33333E-07	0.83336E-09	0.83333E-09
0.33333E-07	0.83336E-09	0.83333E-09	0.33333E-07	0.83336E-09	0.83333E-09
0.33333E-07	0.83336E-09	0.83333E-09	0.33333E-07	0.83336E-09	0.83333E-09

COEFFICIENTS B, READ ROW WISE

-0.10000E-07	0.22500E-07	0.22500E-07	-0.10000E-07	0.22500E-07	0.22500E-07
-0.10000E-07	0.22500E-07	0.22500E-07	-0.10000E-07	0.22500E-07	0.22500E-07
-0.10000E-07	0.22500E-07	0.22500E-07	-0.10000E-07	0.22500E-07	0.22500E-07
-0.10000E-07	0.22500E-07	0.22500E-07	-0.10000E-07	0.22500E-07	0.22500E-07
-0.10000E-07	0.22500E-07	0.22500E-07	-0.10000E-07	0.22500E-07	0.22500E-07
-0.10000E-07	0.22500E-07	0.22500E-07	-0.10000E-07	0.22500E-07	0.22500E-07

COEFFICIENTS C, READ ROW WISE

-0.0	0.37528E-07	-0.37528E-07	-0.0	0.37528E-07	-0.37528E-07
-0.0	0.37528E-07	-0.37528E-07	-0.0	0.37528E-07	-0.37528E-07
-0.0	0.37528E-07	-0.37528E-07	-0.0	0.37528E-07	-0.37528E-07
-0.0	0.37528E-07	-0.37528E-07	-0.0	0.37528E-07	-0.37528E-07
-0.0	0.37528E-07	-0.37528E-07	-0.0	0.37528E-07	-0.37528E-07
-0.0	0.37528E-07	-0.37528E-07	-0.0	0.37528E-07	-0.37528E-07

EXPANSION WITH 11 FOURIER COEFFICIENTS

KS = 0   KS IS AN INDEX INDICATING TYPE OF SOLUTION: 0 FOR NORMAL, 1 FOR SINGULAR

Note: If the system of equations for the Fourier coefficients is singluar, this fact is signaled by KS = 1. Any output which follows is invalid.

FOURIER COEFFICIENTS

	CONSTANTS
TANG.	0.45455E 03
LONG.	0.28943E 01
SHEAR	0.56926E 00

	COS 1(THETA)	SIN 1(THETA)	COS 2(THETA)	SIN 2(THETA)	COS 3(THETA)	SIN 3(THETA)
TANG.	-0.51868E-03	-0.95258E-04	0.16030E-04	-0.52048E-04	0.94102E-05	-0.21859E-04
LONG.	-0.11386E 01	0.11385E 01	-0.83788E-04	-0.39759E-04	-0.68131E-04	-0.23244E-04
SHEAR	0.53861E 01	-0.53860E 01	0.82367E-05	0.46219E-05	-0.20428E-05	-0.13867E-05

	COS 4(THETA)	SIN 4(THETA)	COS 5(THETA)	SIN 5(THETA)
TANG.	0.38785E-04	-0.16227E-05	-0.13316E-05	0.42612E-04
LONG.	-0.59643E-04	-0.35988E-04	0.16735E-06	0.61955E-04
SHEAR	0.56175E-06	-0.41939E-06	0.42750E-06	-0.26063E-06

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THETA =   0 DEGREES       POINT NO.   1
STRESSES          TANG.                LONG.                 SHEAR
ACTUAL          0.45455E 03        0.17552E 01         0.59553E 01
COMPUTED        0.45455E 03        0.17554E 01         0.59553E 01

THETA =  10 DEGREES       POINT NO.  11
STRESSES          TANG.                LONG.                 SHEAR
ACTUAL          0.45455E 03        0.19702E 01         0.49382E 01
COMPUTED        0.45455E 03        0.19704E 01         0.49382E 01

THETA =  20 DEGREES       POINT NO.  21
STRESSES          TANG.                LONG.                 SHEAR
ACTUAL          0.45455E 03        0.22133E 01         0.37884E 01
COMPUTED        0.45455E 03        0.22135E 01         0.37884E 01

THETA =  30 DEGREES       POINT NO.  31
STRESSES          TANG.                LONG.                 SHEAR
ACTUAL          0.45455E 03        0.24770E 01         0.25407E 01
COMPUTED        0.45454E 03        0.24773E 01         0.25407E 01

THETA =  40 DEGREES       POINT NO.  41
STRESSES          TANG.                LONG.                 SHEAR
ACTUAL          0.45455E 03        0.27534E 01         0.12331E 01
COMPUTED        0.45454E 03        0.27538E 01         0.12331E 01

THETA =  50 DEGREES       POINT NO.  51
STRESSES          TANG.                LONG.                 SHEAR
ACTUAL          0.45455E 03        0.30341E 01        -0.94609E-01
COMPUTED        0.45454E 03        0.30345E 01        -0.94599E-01

THETA =  60 DEGREES       POINT NO.  61
STRESSES          TANG.                LONG.                 SHEAR
ACTUAL          0.45455E 03        0.33104E 01        -0.14022E 01
COMPUTED        0.45455E 03        0.33110E 01        -0.14022E 01

THETA =  70 DEGREES       POINT NO.  71
STRESSES          TANG.                LONG.                 SHEAR
ACTUAL          0.45455E 03        0.35742E 01        -0.26498E 01
COMPUTED        0.45455E 03        0.35748E 01        -0.26498E 01

THETA =  80 DEGREES       POINT NO.  81
STRESSES          TANG.                LONG.                 SHEAR
ACTUAL          0.45455E 03        0.38172E 01        -0.37997E 01
COMPUTED        0.45455E 03        0.38178E 01        -0.37997E 01

THETA =  90 DEGREES       POINT NO.  91
STRESSES          TANG.                LONG.                 SHEAR
ACTUAL          0.45455E 03        0.40322E 01        -0.48168E 01
COMPUTED        0.45455E 03        0.40328E 01        -0.48168E 01

THETA = 100 DEGREES       POINT NO. 101
STRESSES          TANG.                LONG.                 SHEAR
ACTUAL          0.45455E 03        0.42126E 01        -0.56702E 01
COMPUTED        0.45455E 03        0.42132E 01        -0.56702E 01

THETA = 110 DEGREES       POINT NO. 111
STRESSES          TANG.                LONG.                 SHEAR
ACTUAL          0.45455E 03        0.43530E 01        -0.63341E 01
COMPUTED        0.45455E 03        0.43535E 01        -0.63341E 01
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THETA = 120 DEGREES       POINT NO. 121
STRESSES          TANG.                LONG.                  SHEAR
ACTUAL          0.45455E 03         0.44490E 01          -0.67882E 01
COMPUTED        0.45455E 03         0.44495E 01          -0.67882E 01

THETA = 130 DEGREES       POINT NO. 131
STRESSES          TANG.                LONG.                  SHEAR
ACTUAL          0.45455E 03         0.44977E 01          -0.70188E 01
COMPUTED        0.45455E 03         0.44982E 01          -0.70188E 01

THETA = 140 DEGREES       POINT NO. 141
STRESSES          TANG.                LONG.                  SHEAR
ACTUAL          0.45455E 03         0.44977E 01          -0.70188E 01
COMPUTED        0.45455E 03         0.44983E 01          -0.70188E 01

THETA = 150 DEGREES       POINT NO. 151
STRESSES          TANG.                LONG.                  SHEAR
ACTUAL          0.45455E 03         0.44490E 01          -0.67882E 01
COMPUTED        0.45455E 03         0.44496E 01          -0.67882E 01

THETA = 160 DEGREES       POINT NO. 161
STRESSES          TANG.                LONG.                  SHEAR
ACTUAL          0.45455E 03         0.43530E 01          -0.63341E 01
COMPUTED        0.45455E 03         0.43537E 01          -0.63341E 01

THETA = 170 DEGREES       POINT NO. 171
STRESSES          TANG.                LONG.                  SHEAR
ACTUAL          0.45455E 03         0.42126E 01          -0.56703E 01
COMPUTED        0.45455E 03         0.42133E 01          -0.56702E 01

THETA = 180 DEGREES       POINT NO. 181
STRESSES          TANG.                LONG.                  SHEAR
ACTUAL          0.45455E 03         0.40322E 01          -0.48168E 01
COMPUTED        0.45455E 03         0.40328E 01          -0.48168E 01

THETA = 190 DEGREES       POINT NO. 191
STRESSES          TANG.                LONG.                  SHEAR
ACTUAL          0.45455E 03         0.38172E 01          -0.37997E 01
COMPUTED        0.45455E 03         0.38178E 01          -0.37997E 01

THETA = 200 DEGREES       POINT NO. 201
STRESSES          TANG.                LONG.                  SHEAR
ACTUAL          0.45455E 03         0.35742E 01          -0.26498E 01
COMPUTED        0.45455E 03         0.35747E 01          -0.26498E 01

THETA = 210 DEGREES       POINT NO. 211
STRESSES          TANG.                LONG.                  SHEAR
ACTUAL          0.45455E 03         0.33105E 01          -0.14022E 01
COMPUTED        0.45455E 03         0.33110E 01          -0.14022E 01

THETA = 220 DEGREES       POINT NO. 221
STRESSES          TANG.                LONG.                  SHEAR
ACTUAL          0.45455E 03         0.30341E 01          -0.94623E-01
COMPUTED        0.45455E 03         0.30347E 01          -0.94618E-01

THETA = 230 DEGREES       POINT NO. 231
STRESSES          TANG.                LONG.                  SHEAR
ACTUAL          0.45455E 03         0.27534E 01           0.12331E 01
COMPUTED        0.45455E 03         0.27541E 01           0.12331E 01
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THETA = 240 DEGREES     POINT NO. 241
STRESSES          TANG.               LONG.                 SHEAR
ACTUAL        0.45455E 03        0.24770E 01          0.25407E 01
COMPUTED      0.45455E 03        0.24777E 01          0.25407E 01

THETA = 250 DEGREES     POINT NO. 251
STRESSES          TANG.               LONG.                 SHEAR
ACTUAL        0.45455E 03        0.22133E 01          0.37883E 01
COMPUTED      0.45455E 03        0.22139E 01          0.37883E 01

THETA = 260 DEGREES     POINT NO. 261
STRESSES          TANG.               LONG.                 SHEAR
ACTUAL        0.45455E 03        0.19702E 01          0.49382E 01
COMPUTED      0.45455E 03        0.19708E 01          0.49382E 01

THETA = 270 DEGREES     POINT NO. 271
STRESSES          TANG.               LONG.                 SHEAR
ACTUAL        0.45455E 03        0.17552E 01          0.59553E 01
COMPUTED      0.45455E 03        0.17558E 01          0.59553E 01

THETA = 280 DEGREES     POINT NO. 281
STRESSES          TANG.               LONG.                 SHEAR
ACTUAL        0.45455E 03        0.15748E 01          0.68088E 01
COMPUTED      0.45455E 03        0.15754E 01          0.68087E 01

THETA = 290 DEGREES     POINT NO. 291
STRESSES          TANG.               LONG.                 SHEAR
ACTUAL        0.45455E 03        0.14345E 01          0.74726E 01
COMPUTED      0.45455E 03        0.14351E 01          0.74726E 01

THETA = 300 DEGREES     POINT NO. 301
STRESSES          TANG.               LONG.                 SHEAR
ACTUAL        0.45455E 03        0.13385E 01          0.79267E 01
COMPUTED      0.45455E 03        0.13392E 01          0.79267E 01

THETA = 310 DEGREES     POINT NO. 311
STRESSES          TANG.               LONG.                 SHEAR
ACTUAL        0.45455E 03        0.12898E 01          0.81573E 01
COMPUTED      0.45455E 03        0.12905E 01          0.81573E 01

THETA = 320 DEGREES     POINT NO. 321
STRESSES          TANG.               LONG.                 SHEAR
ACTUAL        0.45455E 03        0.12897E 01          0.81573E 01
COMPUTED      0.45455E 03        0.12904E 01          0.81573E 01

THETA = 330 DEGREES     POINT NO. 331
STRESSES          TANG.               LONG.                 SHEAR
ACTUAL        0.45455E 03        0.13385E 01          0.79267E 01
COMPUTED      0.45455E 03        0.13390E 01          0.79267E 01

THETA = 340 DEGREES     POINT NO. 341
STRESSES          TANG.               LONG.                 SHEAR
ACTUAL        0.45455E 03        0.14345E 01          0.74726E 01
COMPUTED      0.45455E 03        0.14348E 01          0.74726E 01

THETA = 350 DEGREES     POINT NO. 351
STRESSES          TANG.               LONG.                 SHEAR
ACTUAL        0.45455E 03        0.15748E 01          0.68088E 01
COMPUTED      0.45455E 03        0.15751E 01          0.68088E 01
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EXPANSION WITH  3  FOURIER COEFFICIENTS

KS = 0    KS IS AN INDEX INDICATING TYPE OF SOLUTION: 0 FOR NORMAL, 1 FOR SINGULAR

FOURIER COEFFICIENTS

          CONSTANTS
TANG.     0.45455E 03
LONG.     0.28943E 01
SHEAR     0.56926E 00

         COS 1(THETA)   SIN 1(THETA)
TANG.   -0.51868E-03   -0.95258E-04
LONG.   -0.11386E 01    0.11385E 01
SHEAR    0.53861E 01   -0.53860E 01
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THETA =   0 DEGREES        POINT NO.    1
STRESSES           TANG.                LONG.                  SHEAR
ACTUAL          0.45455E 03       0.17552E 01         0.59553E 01
COMPUTED        0.45455E 03       0.17556E 01         0.59553E 01

THETA =  10 DEGREES        POINT NO.   11
STRESSES           TANG.                LONG.                  SHEAR
ACTUAL          0.45455E 03       0.19702E 01         0.49382E 01
COMPUTED        0.45455E 03       0.19706E 01         0.49382E 01

THETA =  20 DEGREES        POINT NO.   21
STRESSES           TANG.                LONG.                  SHEAR
ACTUAL          0.45455E 03       0.22133E 01         0.37884E 01
COMPUTED        0.45455E 03       0.22137E 01         0.37884E 01

THETA =  30 DEGREES        POINT NO.   31
STRESSES           TANG.                LONG.                  SHEAR
ACTUAL          0.45455E 03       0.24770E 01         0.25407E 01
COMPUTED        0.45455E 03       0.24774E 01         0.25407E 01

THETA =  40 DEGREES        POINT NO.   41
STRESSES           TANG.                LONG.                  SHEAR
ACTUAL          0.45455E 03       0.27534E 01         0.12331E 01
COMPUTED        0.45455E 03       0.27538E 01         0.12331E 01

THETA =  50 DEGREES        POINT NO.   51
STRESSES           TANG.                LONG.                  SHEAR
ACTUAL          0.45455E 03       0.30341E 01        -0.94609E-01
COMPUTED        0.45455E 03       0.30345E 01        -0.94604E-01

THETA =  60 DEGREES        POINT NO.   61
STRESSES           TANG.                LONG.                  SHEAR
ACTUAL          0.45455E 03       0.33104E 01        -0.14022E 01
COMPUTED        0.45455E 03       0.33109E 01        -0.14022E 01

THETA =  70 DEGREES        POINT NO.   71
STRESSES           TANG.                LONG.                  SHEAR
ACTUAL          0.45455E 03       0.35742E 01        -0.26498E 01
COMPUTED        0.45455E 03       0.35746E 01        -0.26498E 01

THETA =  80 DEGREES        POINT NO.   81
STRESSES           TANG.                LONG.                  SHEAR
ACTUAL          0.45455E 03       0.38172E 01        -0.37997E 01
COMPUTED        0.45455E 03       0.38177E 01        -0.37997E 01

THETA =  90 DEGREES        POINT NO.   91
STRESSES           TANG.                LONG.                  SHEAR
ACTUAL          0.45455E 03       0.40322E 01        -0.48168E 01
COMPUTED        0.45455E 03       0.40327E 01        -0.48168E 01

THETA = 100 DEGREES        POINT NO.  101
STRESSES           TANG.                LONG.                  SHEAR
ACTUAL          0.45455E 03       0.42126E 01        -0.56702E 01
COMPUTED        0.45455E 03       0.42132E 01        -0.56702E 01

THETA = 110 DEGREES        POINT NO.  111
STRESSES           TANG.                LONG.                  SHEAR
ACTUAL          0.45455E 03       0.43530E 01        -0.63341E 01
COMPUTED        0.45455E 03       0.43535E 01        -0.63341E 01
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THETA = 120 DEGREES POINT NO. 121

STRESSES	TANG.	LONG.	SHEAR
ACTUAL	0.45455E 03	0.44490E 01	-0.67882E 01
COMPUTED	0.45455E 03	0.44495E 01	-0.67882E 01

THETA = 130 DEGREES POINT NO. 131

STRESSES	TANG.	LONG.	SHEAR
ACTUAL	0.45455E 03	0.44977E 01	-0.70188E 01
COMPUTED	0.45455E 03	0.44983E 01	-0.70188E 01

THETA = 140 DEGREES POINT NO. 141

STRESSES	TANG.	LONG.	SHEAR
ACTUAL	0.45455E 03	0.44977E 01	-0.70188E 01
COMPUTED	0.45455E 03	0.44983E 01	-0.70188E 01

THETA = 150 DEGREES POINT NO. 151

STRESSES	TANG.	LONG.	SHEAR
ACTUAL	0.45455E 03	0.44490E 01	-0.67882E 01
COMPUTED	0.45455E 03	0.44496E 01	-0.67882E 01

THETA = 160 DEGREES POINT NO. 161

STRESSES	TANG.	LONG.	SHEAR
ACTUAL	0.45455E 03	0.43530E 01	-0.63341E 01
COMPUTED	0.45455E 03	0.43536E 01	-0.63341E 01

THETA = 170 DEGREES POINT NO. 171

STRESSES	TANG.	LONG.	SHEAR
ACTUAL	0.45455E 03	0.42126E 01	-0.56703E 01
COMPUTED	0.45455E 03	0.42133E 01	-0.56702E 01

THETA = 180 DEGREES POINT NO. 181

STRESSES	TANG.	LONG.	SHEAR
ACTUAL	0.45455E 03	0.40322E 01	-0.48168E 01
COMPUTED	0.45455E 03	0.40329E 01	-0.48168E 01

THETA = 190 DEGREES POINT NO. 191

STRESSES	TANG.	LONG.	SHEAR
ACTUAL	0.45455E 03	0.38172E 01	-0.37997E 01
COMPUTED	0.45455E 03	0.38179E 01	-0.37997E 01

THETA = 200 DEGREES POINT NO. 201

STRESSES	TANG.	LONG.	SHEAR
ACTUAL	0.45455E 03	0.35742E 01	-0.26498E 01
COMPUTED	0.45455E 03	0.35749E 01	-0.26498E 01

THETA = 210 DEGREES POINT NO. 211

STRESSES	TANG.	LONG.	SHEAR
ACTUAL	0.45455E 03	0.33105E 01	-0.14022E 01
COMPUTED	0.45455E 03	0.33111E 01	-0.14022E 01

THETA = 220 DEGREES POINT NO. 221

STRESSES	TANG.	LONG.	SHEAR
ACTUAL	0.45455E 03	0.30341E 01	-0.94623E-01
COMPUTED	0.45455E 03	0.30347E 01	-0.94625E-01

THETA = 230 DEGREES POINT NO. 231

STRESSES	TANG.	LONG.	SHEAR
ACTUAL	0.45455E 03	0.27534E 01	0.12331E 01
COMPUTED	0.45455E 03	0.27541E 01	0.12331E 01

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THETA = 240 DEGREES      POINT NO. 241
STRESSES            TANG.            LONG.                SHEAR
ACTUAL           0.45455E 03      0.24770E 01          0.25407E 01
COMPUTED         0.45455E 03      0.24777E 01          0.25407E 01

THETA = 250 DEGREES      POINT NO. 251
STRESSES            TANG.            LONG.                SHEAR
ACTUAL           0.45455E 03      0.22133E 01          0.37883E 01
COMPUTED         0.45455E 03      0.22139E 01          0.37883E 01

THETA = 260 DEGREES      POINT NO. 261
STRESSES            TANG.            LONG.                SHEAR
ACTUAL           0.45455E 03      0.19702E 01          0.49382E 01
COMPUTED         0.45455E 03      0.19708E 01          0.49382E 01

THETA = 270 DEGREES      POINT NO. 271
STRESSES            TANG.            LONG.                SHEAR
ACTUAL           0.45455E 03      0.17552E 01          0.59553E 01
COMPUTED         0.45455E 03      0.17558E 01          0.59553E 01

THETA = 280 DEGREES      POINT NO. 281
STRESSES            TANG.            LONG.                SHEAR
ACTUAL           0.45455E 03      0.15748E 01          0.68088E 01
COMPUTED         0.45455E 03      0.15754E 01          0.68087E 01

THETA = 290 DEGREES      POINT NO. 291
STRESSES            TANG.            LONG.                SHEAR
ACTUAL           0.45455E 03      0.14345E 01          0.74726E 01
COMPUTED         0.45455E 03      0.14350E 01          0.74726E 01

THETA = 300 DEGREES      POINT NO. 301
STRESSES            TANG.            LONG.                SHEAR
ACTUAL           0.45455E 03      0.13385E 01          0.79267E 01
COMPUTED         0.45455E 03      0.13390E 01          0.79267E 01

THETA = 310 DEGREES      POINT NO. 311
STRESSES            TANG.            LONG.                SHEAR
ACTUAL           0.45455E 03      0.12898E 01          0.81573E 01
COMPUTED         0.45455E 03      0.12903E 01          0.81573E 01

THETA = 320 DEGREES      POINT NO. 321
STRESSES            TANG.            LONG.                SHEAR
ACTUAL           0.45455E 03      0.12897E 01          0.81573E 01
COMPUTED         0.45455E 03      0.12902E 01          0.81573E 01

THETA = 330 DEGREES      POINT NO. 331
STRESSES            TANG.            LONG.                SHEAR
ACTUAL           0.45455E 03      0.13385E 01          0.79267E 01
COMPUTED         0.45455E 03      0.13390E 01          0.79267E 01

THETA = 340 DEGREES      POINT NO. 341
STRESSES            TANG.            LONG.                SHEAR
ACTUAL           0.45455E 03      0.14345E 01          0.74726E 01
COMPUTED         0.45455E 03      0.14349E 01          0.74726E 01

THETA = 350 DEGREES      POINT NO. 351
STRESSES            TANG.            LONG.                SHEAR
ACTUAL           0.45455E 03      0.15748E 01          0.68088E 01
COMPUTED         0.45455E 03      0.15752E 01          0.68088E 01
```

MODULUS OF ELASTICITY 0.30000E 08PSI
SHEAR MODULUS OF ELASTICITY 0.11538E 08 PSI
POISSON RATIO 0.30000E 00

NUMBER OF GAGES 36
TRANSVERSE SENSITIVITY FACTOR OF THE GAGES = 0 %
NUMBER OF GAGES FUNCTIONING PROPERLY 30
GAGES FUNCTIONING IMPROPERLY 2, 12, 22, 24, 25, 33,

ANGULAR POSITION OF THE GAGE IN THE CROSS SECTION, READ ROW WISE

0.0	0.0	0.30000E 02	0.30000E 02	0.30000E 02	0.60000E 02
0.60000E 02	0.60000E 02	0.90000E 02	0.90000E 02	0.12000E 03	0.12000E 03
0.12000E 03	0.15000E 03	0.15000E 03	0.15000E 03	0.18000E 03	0.18000E 03
0.18000E 03	0.21000E 03	0.24000E 03	0.24000E 03	0.27000E 03	0.27000E 03
0.27000E 03	0.30000E 03	0.30000E 03	0.33000E 03	0.33000E 03	0.33000E 03

ANGULAR ORIENTATION OF THE GAGES, READ ROW WISE

0.0	0.12000E 03	0.0	0.60000E 02	0.12000E 03	0.0
0.60000E 02	0.12000E 03	0.0	0.60000E 02	0.0	0.60000E 02
0.12000E 03	0.0	0.60000E 02	0.12000E 03	0.0	0.60000E 02
0.12000E 03	0.60000E 02	0.60000E 02	0.12000E 03	0.0	0.60000E 02
0.12000E 03	0.0	0.60000E 02	0.0	0.60000E 02	0.12000E 03

READINGS OF THE GAGE ELEMENTS, READ ROW WISE. ERROR ADDED 0%

0.15134E-04	0.19479E-06	0.15127E-04	0.52988E-06	0.33917E-06	0.15118E-04
0.40066E-06	0.50589E-06	0.15111E-04	0.28876E-06	0.15107E-04	0.22415E-06
0.73364E-06	0.15107E-04	0.22415E-06	0.73364E-06	0.15111E-04	0.28876E-06
0.65028E-06	0.40066E-06	0.52988E-06	0.33917E-06	0.15134E-04	0.64178E-06
0.19479E-06	0.15138E-04	0.70639E-06	0.15138E-04	0.70639E-06	0.11143E-06

COEFFICIENTS A, READ ROW WISE

0.33333E-07	0.83333E-09	0.33333E-07	0.83336E-09	0.83333E-09	0.33333E-07
0.83336E-09	0.83333E-09	0.33333E-07	0.83336E-09	0.33333E-07	0.83336E-09
0.83333E-09	0.33333E-07	0.83336E-09	0.83333E-09	0.33333E-07	0.83336E-09
0.83333E-09	0.83336E-09	0.83336E-09	0.83333E-09	0.33333E-07	0.83336E-09
0.83333E-09	0.33333E-07	0.83336E-09	0.33333E-07	0.83336E-09	0.83333E-09

COEFFICIENTS B, READ ROW WISE

-0.10000E-07	0.22500E-07	-0.10000E-07	0.22500E-07	0.22500E-07	-0.10000E-07
0.22500E-07	0.22500E-07	-0.10000E-07	0.22500E-07	-0.10000E-07	0.22500E-07
0.22500E-07	-0.10000E-07	0.22500E-07	0.22500E-07	-0.10000E-07	0.22500E-07
0.22500E-07	0.22500E-07	0.22500E-07	0.22500E-07	-0.10000E-07	0.22500E-07
0.22500E-07	-0.10000E-07	0.22500E-07	-0.10000E-07	0.22500E-07	0.22500E-07

COEFFICIENTS C, READ ROW WISE

-0.0	-0.37528E-07	-0.0	0.37528E-07	-0.37528E-07	-0.0
0.37528E-07	-0.37528E-07	-0.0	0.37528E-07	-0.0	0.37528E-07
-0.37528E-07	-0.0	0.37528E-07	-0.37528E-07	-0.0	0.37528E-07
-0.37528E-07	0.37528E-07	0.37528E-07	-0.37528E-07	-0.0	0.37528E-07
-0.37528E-07	-0.0	0.37528E-07	-0.0	0.37528E-07	-0.37528E-07

```
EXPANSION WITH  3  FOURIER COEFFICIENTS

KS = 0    KS IS AN INDEX INDICATING TYPE OF SOLUTION: 0 FOR NORMAL, 1 FOR SINGULAR

FOURIER COEFFICIENTS

         CONSTANTS
TANG.    0.45455E 03
LONG.    0.28943E 01
SHEAR    0.56921E 00

        COS 1(THETA)  SIN 1(THETA)
TANG.   -0.94754E-03  -0.57504E-03
LONG.   -0.11387E 01   0.11384E 01
SHEAR    0.53861E 01  -0.53860E 01
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```
THETA =   0 DEGREES      POINT NO.   1
STRESSES          TANG.            LONG.                 SHEAR
ACTUAL        0.45455E 03     0.17552E 01           0.59553E 01
COMPUTED      0.45454E 03     0.17556E 01           0.59553E 01

THETA =  10 DEGREES      POINT NO.  11
STRESSES          TANG.            LONG.                 SHEAR
ACTUAL        0.45455E 03     0.19702E 01           0.49382E 01
COMPUTED      0.45454E 03     0.19706E 01           0.49382E 01

THETA =  20 DEGREES      POINT NO.  21
STRESSES          TANG.            LONG.                 SHEAR
ACTUAL        0.45455E 03     0.22133E 01           0.37884E 01
COMPUTED      0.45454E 03     0.22136E 01           0.37884E 01

THETA =  30 DEGREES      POINT NO.  31
STRESSES          TANG.            LONG.                 SHEAR
ACTUAL        0.45455E 03     0.24770E 01           0.25407E 01
COMPUTED      0.45454E 03     0.24774E 01           0.25407E 01

THETA =  40 DEGREES      POINT NO.  41
STRESSES          TANG.            LONG.                 SHEAR
ACTUAL        0.45455E 03     0.27534E 01           0.12331E 01
COMPUTED      0.45454E 03     0.27538E 01           0.12331E 01

THETA =  50 DEGREES      POINT NO.  51
STRESSES          TANG.            LONG.                 SHEAR
ACTUAL        0.45455E 03     0.30341E 01         -0.94609E-01
COMPUTED      0.45454E 03     0.30344E 01         -0.94596E-01

THETA =  60 DEGREES      POINT NO.  61
STRESSES          TANG.            LONG.                 SHEAR
ACTUAL        0.45455E 03     0.33104E 01          -0.14022E 01
COMPUTED      0.45454E 03     0.33108E 01          -0.14022E 01

THETA =  70 DEGREES      POINT NO.  71
STRESSES          TANG.            LONG.                 SHEAR
ACTUAL        0.45455E 03     0.35742E 01          -0.26498E 01
COMPUTED      0.45454E 03     0.35746E 01          -0.26498E 01

THETA =  80 DEGREES      POINT NO.  81
STRESSES          TANG.            LONG.                 SHEAR
ACTUAL        0.45455E 03     0.38172E 01          -0.37997E 01
COMPUTED      0.45454E 03     0.38177E 01          -0.37997E 01

THETA =  90 DEGREES      POINT NO.  91
STRESSES          TANG.            LONG.                 SHEAR
ACTUAL        0.45455E 03     0.40322E 01          -0.48168E 01
COMPUTED      0.45454E 03     0.40327E 01          -0.48168E 01

THETA = 100 DEGREES      POINT NO. 101
STRESSES          TANG.            LONG.                 SHEAR
ACTUAL        0.45455E 03     0.42126E 01          -0.56702E 01
COMPUTED      0.45454E 03     0.42131E 01          -0.56703E 01

THETA = 110 DEGREES      POINT NO. 111
STRESSES          TANG.            LONG.                 SHEAR
ACTUAL        0.45455E 03     0.43530E 01          -0.63341E 01
COMPUTED      0.45455E 03     0.43535E 01          -0.63341E 01
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MODULUS OF ELASTICITY  0.30000E 08PSI
SHEAR MODULUS OF ELASTICITY  0.11538E 08 PSI
POISSON RATIO  0.30000E 00

NUMBER OF GAGES  36
TRANSVERSE SENSITIVITY FACTOR OF THE GAGES = 0  %
NUMBER OF GAGES FUNCTIONING PROPERLY  36
GAGES FUNCTIONING IMPROPERLY ... NONE
```

ANGULAR POSITION OF THE GAGE IN THE CROSS SECTION, READ ROW WISE

0.0	0.0	0.0	0.30000E 02	0.30000E 02	0.30000E 02
0.60000E 02	0.60000E 02	0.60000E 02	0.90000E 02	0.90000E 02	0.90000E 02
0.12000E 03	0.12000E 03	0.12000E 03	0.15000E 03	0.15000E 03	0.15000E 03
0.18000E 03	0.18000E 03	0.18000E 03	0.21000E 03	0.21000E 03	0.21000E 03
0.24000E 03	0.24000E 03	0.24000E 03	0.27000E 03	0.27000E 03	0.27000E 03
0.30000E 03	0.30000E 03	0.30000E 03	0.33000E 03	0.33000E 03	0.33000E 03

ANGULAR ORIENTATION OF THE GAGES, READ ROW WISE

0.0	0.60000E 02	0.12000E 03	0.0	0.60000E 02	0.12000E 03
0.0	0.60000E 02	0.12000E 03	0.0	0.60000E 02	0.12000E 03
0.0	0.60000E 02	0.12000E 03	0.0	0.60000E 02	0.12000E 03
0.0	0.60000E 02	0.12000E 03	0.0	0.60000E 02	0.12000E 03
0.0	0.60000E 02	0.12000E 03	0.0	0.60000E 02	0.12000E 03
0.0	0.60000E 02	0.12000E 03	0.0	0.60000E 02	0.12000E 03

READINGS OF THE GAGE ELEMENTS, READ ROW WISE. ERROR ADDED 2%

0.15134E-04	0.63164E-06	0.19596E-06	0.14907E-04	0.53904E-06	0.33688E-06
0.14833E-04	0.40585E-06	0.50206E-06	0.15126E-04	0.29224E-06	0.63844E-06
0.15008E-04	0.22246E-06	0.73175E-06	0.14883E-04	0.22505E-06	0.73152E-06
0.15183E-04	0.29368E-06	0.64296E-06	0.14880E-04	0.40417E-06	0.49667E-06
0.14843E-04	0.53846E-06	0.33419E-06	0.15091E-04	0.64980E-06	0.19406E-06
0.15088E-04	0.71787E-06	0.11202E-06	0.15327E-04	0.71808E-06	0.11338E-06

EXPANSION WITH 11 FOURIER COEFFICIENTS

KS = 0 KS IS AN INDEX INDICATING TYPE OF SOLUTION: 0 FOR NORMAL, 1 FOR SINGULAR

FOURIER COEFFICIENTS

	CONSTANTS
TANG.	0.45167E 03
LONG.	0.30279E 01
SHEAR	0.67538E 00

	COS 1(THETA)	SIN 1(THETA)	COS 2(THETA)	SIN 2(THETA)	COS 3(THETA)	SIN 3(THETA)
TANG.	0.16451E 01	-0.94166E 00	0.10407E 01	-0.36258E 01	-0.60751E 00	-0.22247E 01
LONG.	-0.11111E 01	0.10538E 01	-0.76545E-01	0.86755E-01	-0.51607E-01	0.13186E 00
SHEAR	0.53511E 01	-0.54097E 01	-0.47720E-01	0.44068E-01	-0.65953E-01	-0.32323E-01

	COS 4(THETA)	SIN 4(THETA)	COS 5(THETA)	SIN 5(THETA)
TANG.	0.31820E 01	-0.17485E-01	-0.21132E 01	-0.46379E 00
LONG.	-0.21402E 00	-0.24257E-01	-0.92955E-02	0.12406E-01
SHEAR	-0.22891E-01	-0.17709E-03	-0.55914E-01	0.34983E-01

```
THETA = 240 DEGREES      POINT NO. 241
STRESSES          TANG.              LONG.                 SHEAR
ACTUAL       0.45455E C3       0.24770E 01          0.25407E 01
COMPUTED     0.44647E C3       0.28761E 01          0.27506E 01

THETA = 250 DEGREES      POINT NO. 251
STRESSES          TANG.              LONG.                 SHEAR
ACTUAL       0.45455E C3       0.22133E 01          0.37883E 01
COMPUTED     0.44979E C3       0.25514E 01          0.39775E 01

THETA = 260 DEGREES      POINT NO. 261
STRESSES          TANG.              LONG.                 SHEAR
ACTUAL       0.45455E C3       0.19702E 01          0.49382E 01
COMPUTED     0.45222E 03       0.22239E 01          0.50755E 01

THETA = 270 DEGREES      POINT NO. 271
STRESSES          TANG.              LONG.                 SHEAR
ACTUAL       0.45455E C3       0.17552E 01          0.59553E 01
COMPUTED     0.45299E 03       0.19561E 01          0.60426E 01

THETA = 280 DEGREES      POINT NO. 281
STRESSES          TANG.              LONG.                 SHEAR
ACTUAL       0.45455E C3       0.15748E 01          0.68088E 01
COMPUTED     0.45262E 03       0.17848E 01          0.68838E 01

THETA = 290 DEGREES      POINT NO. 291
STRESSES          TANG.              LONG.                 SHEAR
ACTUAL       0.45455E C3       0.14345E 01          0.74726E 01
COMPUTED     0.45243E C3       0.17031E 01          0.75850E 01

THETA = 300 DEGREES      POINT NO. 301
STRESSES          TANG.              LONG.                 SHEAR
ACTUAL       0.45455E C3       0.13385E 01          0.79267E 01
COMPUTED     0.45347E C3       0.16666E 01          0.81011E 01

THETA = 310 DEGREES      POINT NO. 311
STRESSES          TANG.              LONG.                 SHEAR
ACTUAL       0.45455E C3       0.12898E 01          0.81573E 01
COMPUTED     0.45576E C3       0.16207E 01          0.83706E 01

THETA = 320 DEGREES      POINT NO. 321
STRESSES          TANG.              LONG.                 SHEAR
ACTUAL       0.45455E C3       0.12897E 01          0.81573E 01
COMPUTED     0.45836E C3       0.15346E 01          0.83472E 01

THETA = 330 DEGREES      POINT NO. 331
STRESSES          TANG.              LONG.                 SHEAR
ACTUAL       0.45455E C3       0.13385E 01          0.79267E 01
COMPUTED     0.45993E C3       0.14234E 01          0.80272E 01

THETA = 340 DEGREES      POINT NO. 341
STRESSES          TANG.              LONG.                 SHEAR
ACTUAL       0.45455E C3       0.14345E 01          0.74726E 01
COMPUTED     0.45968E C3       0.13451E 01          0.74556E 01

THETA = 350 DEGREES      POINT NO. 351
STRESSES          TANG.              LONG.                 SHEAR
ACTUAL       0.45455E C3       0.15748E 01          0.68088E 01
COMPUTED     0.45770E C3       0.13746E 01          0.67035E 01
```

EXPANSION WITH 5 FOURIER COEFFICIENTS

KS = 0   KS IS AN INDEX INDICATING TYPE OF SOLUTION: 0 FOR NORMAL, 1 FOR SINGULAR

FOURIER COEFFICIENTS

	CONSTANTS
TANG.	0.45167E 03
LONG.	0.30279E 01
SHEAR	0.67538E 00

	COS 1(THETA)	SIN 1(THETA)	COS 2(THETA)	SIN 2(THETA)
TANG.	0.16451E 01	-0.94167E 00	0.10407E 01	-0.36258E 01
LONG.	-0.11111E 01	0.10538E 01	-0.76546E-01	0.86754E-01
SHEAR	0.53511E 01	-0.54097E 01	-0.47720E-01	0.44068E-01

```
THETA = 240 DEGREES     POINT NO. 241
STRESSES          TANG.            LONG.                 SHEAR
ACTUAL        0.45455E 03    0.24770E 01          0.25407E 01
COMPUTED      0.44800E 03    0.27843E 01          0.27467E 01

THETA = 250 DEGREES     POINT NO. 251
STRESSES          TANG.            LONG.                 SHEAR
ACTUAL        0.45455E 03    0.22133E 01          0.37883E 01
COMPUTED      0.44886E 03    0.25321E 01          0.39935E 01

THETA = 260 DEGREES     POINT NO. 261
STRESSES          TANG.            LONG.                 SHEAR
ACTUAL        0.45455E 03    0.19702E 01          0.49382E 01
COMPUTED      0.45009E 03    0.22847E 01          0.51336E 01

THETA = 270 DEGREES     POINT NO. 271
STRESSES          TANG.            LONG.                 SHEAR
ACTUAL        0.45455E 03    0.17552E 01          0.59553E 01
COMPUTED      0.45157E 03    0.20507E 01          0.61327E 01

THETA = 280 DEGREES     POINT NO. 281
STRESSES          TANG.            LONG.                 SHEAR
ACTUAL        0.45455E 03    0.15748E 01          0.68088E 01
COMPUTED      0.45314E 03    0.18395E 01          0.69618E 01

THETA = 290 DEGREES     POINT NO. 291
STRESSES          TANG.            LONG.                 SHEAR
ACTUAL        0.45455E 03    0.14345E 01          0.74726E 01
COMPUTED      0.45465E 03    0.16605E 01          0.75972E 01

THETA = 300 DEGREES     POINT NO. 301
STRESSES          TANG.            LONG.                 SHEAR
ACTUAL        0.45455E 03    0.13385E 01          0.79267E 01
COMPUTED      0.45592E 03    0.15229E 01          0.80215E 01

THETA = 310 DEGREES     POINT NO. 311
STRESSES          TANG.            LONG.                 SHEAR
ACTUAL        0.45455E 03    0.12898E 01          0.81573E 01
COMPUTED      0.45684E 03    0.14343E 01          0.82239E 01

THETA = 320 DEGREES     POINT NO. 321
STRESSES          TANG.            LONG.                 SHEAR
ACTUAL        0.45455E 03    0.12897E 01          0.81573E 01
COMPUTED      0.45728E 03    0.14007E 01          0.82001E 01

THETA = 330 DEGREES     POINT NO. 331
STRESSES          TANG.            LONG.                 SHEAR
ACTUAL        0.45455E 03    0.13385E 01          0.79267E 01
COMPUTED      0.45722E 03    0.14253E 01          0.79524E 01

THETA = 340 DEGREES     POINT NO. 341
STRESSES          TANG.            LONG.                 SHEAR
ACTUAL        0.45455E 03    0.14345E 01          0.74726E 01
COMPUTED      0.45666E 03    0.15090E 01          0.74891E 01

THETA = 350 DEGREES     POINT NO. 351
STRESSES          TANG.            LONG.                 SHEAR
ACTUAL        0.45455E 03    0.15748E 01          0.68088E 01
COMPUTED      0.45567E 03    0.16491E 01          0.68246E 01
```

EXPANSION WITH 3 FOURIER COEFFICIENTS

KS = 0 KS IS AN INDEX INDICATING TYPE OF SOLUTION: 0 FOR NORMAL, 1 FOR SINGULAR

FOURIER COEFFICIENTS

	CONSTANTS
TANG.	0.45167E 03
LONG.	0.30279E 01
SHEAR	0.67538E 00

	COS 1(THETA)	SIN 1(THETA)
TANG.	0.16451E 01	-0.94167E 00
LONG.	-0.11111E 01	0.10538E 01
SHEAR	0.53511E 01	-0.54097E 01

```
THETA = 240 DEGREES     POINT NO. 241
STRESSES          TANG.              LONG.                SHEAR
ACTUAL      0.45455E 03      0.24770E 01        0.25407E 01
COMPUTED    0.45166E 03      0.26709E 01        0.26847E 01

THETA = 250 DEGREES     POINT NO. 251
STRESSES          TANG.              LONG.                SHEAR
ACTUAL      0.45455E 03      0.22133E 01        0.37883E 01
COMPUTED    0.45199E 03      0.24177E 01        0.39286E 01

THETA = 260 DEGREES     POINT NO. 261
STRESSES          TANG.              LONG.                SHEAR
ACTUAL      0.45455E 03      0.19702E 01        0.49382E 01
COMPUTED    0.45231E 03      0.21831E 01        0.50736E 01

THETA = 270 DEGREES     POINT NO. 271
STRESSES          TANG.              LONG.                SHEAR
ACTUAL      0.45455E 03      0.17552E 01        0.59553E 01
COMPUTED    0.45261E 03      0.19741E 01        0.60850E 01

THETA = 280 DEGREES     POINT NO. 281
STRESSES          TANG.              LONG.                SHEAR
ACTUAL      0.45455E 03      0.15748E 01        0.68088E 01
COMPUTED    0.45288E 03      0.17972E 01        0.69321E 01

THETA = 290 DEGREES     POINT NO. 291
STRESSES          TANG.              LONG.                SHEAR
ACTUAL      0.45455E 03      0.14345E 01        0.74726E 01
COMPUTED    0.45311E 03      0.16577E 01        0.75890E 01

THETA = 300 DEGREES     POINT NO. 301
STRESSES          TANG.              LONG.                SHEAR
ACTUAL      0.45455E 03      0.13385E 01        0.79267E 01
COMPUTED    0.45330E 03      0.15597E 01        0.80358E 01

THETA = 310 DEGREES     POINT NO. 311
STRESSES          TANG.              LONG.                SHEAR
ACTUAL      0.45455E 03      0.12898E 01        0.81573E 01
COMPUTED    0.45345E 03      0.15064E 01        0.82590E 01

THETA = 320 DEGREES     POINT NO. 321
STRESSES          TANG.              LONG.                SHEAR
ACTUAL      0.45455E 03      0.12897E 01        0.81573E 01
COMPUTED    0.45353E 03      0.14994E 01        0.82518E 01

THETA = 330 DEGREES     POINT NO. 331
STRESSES          TANG.              LONG.                SHEAR
ACTUAL      0.45455E 03      0.13385E 01        0.79267E 01
COMPUTED    0.45356E 03      0.15388E 01        0.80144E 01

THETA = 340 DEGREES     POINT NO. 341
STRESSES          TANG.              LONG.                SHEAR
ACTUAL      0.45455E 03      0.14345E 01        0.74726E 01
COMPUTED    0.45353E 03      0.16234E 01        0.75540E 01

THETA = 350 DEGREES     POINT NO. 351
STRESSES          TANG.              LONG.                SHEAR
ACTUAL      0.45455E 03      0.15748E 01        0.68088E 01
COMPUTED    0.45345E 03      0.17507E 01        0.68846E 01
```

MODULUS CF ELASTICITY C.30000E 08PSI
SHEAR MODULUS OF ELASTICITY 0.11538E 08 PSI
POISSON RATIO 0.3CCCOE OC

NUMBER OF GAGES 36
TRANSVERSE SENSITIVITY FACTOR OF THE GAGES = 1 %
NUMBER OF GAGES FUNCTIONING PROPERLY 36
GAGES FUNCTIONING IMPROPERLY ... NONE

ANGULAR POSITICN CF THE GAGE IN THE CROSS SECTION, READ ROW WISE

0.C	C.C	0.0	0.30000E 02	0.30000E 02	0.30000E 02
0.60000E 02	C.60000E 02	0.60000E 02	0.90000E 02	0.90000E 02	0.90000E 02
0.12C00E 03	C.12C00E 03	0.12000E 03	0.15000E 03	0.15000E 03	0.15000E 03
0.18000E 03	C.18C00E 03	0.18000E 03	0.21000E 03	0.21000E 03	0.21000E 03
0.240C0E 03	C.24000E 03	0.24000E 03	0.27000E 03	0.27000E 03	0.27000E 03
0.30000E C3	C.30000E C3	0.30000E 03	0.33000E 03	0.33000E 03	0.33000E 03

ANGULAR ORIENTATICN OF THE GAGES, READ ROW WISE

0.0	C.60C00E 02	0.12000E 03	0.0	0.60000E 02	0.12000E 03
0.0	C.60000E 02	0.12000E 03	0.0	0.60000E 02	0.12000E 03
0.C	C.60000E 02	0.12000E 03	0.0	0.60000E 02	0.12000E 03
0.0	C.60C00E 02	0.12000E 03	0.C	0.60000E 02	0.12000E 03
0.C	C.60C00E 02	0.12000E 03	0.0	0.60000E 02	0.12000E 03
0.0	C.60000E 02	0.12000E 03	0.C	0.60000E 02	0.12000E 03

READINGS OF THE GAGE ELEMENTS, READ ROW WISE. ERROR ADDED 0%

0.15091E-04	C.74191E-06	0.29935E-06	0.15084E-04	0.63129E-06	0.44247E-06
0.15076E-04	C.50355E-06	0.60773E-06	0.15069E-04	0.39292E-06	0.75086E-06
0.15065E-04	C.32905E-06	0.83349E-06	0.15065E-04	0.32905E-06	0.83349E-06
0.15069E-04	C.39292E-06	0.75086E-06	0.15076E-04	0.50355E-06	0.60773E-06
0.15084E-04	0.63129E-06	0.44247E-06	0.15091E-04	0.74191E-06	0.29935E-06
0.15095E-04	C.80579E-06	0.21672E-06	0.15095E-04	0.80579E-06	0.21672E-06

COEFFICIENTS A, READ ROW WISE

0.33237E-07	0.10585E-08	0.10585E-08	0.33237E-07	0.10585E-08	0.10585E-08
0.33237E-07	0.10585E-08	0.10585E-08	0.33237E-07	0.10585E-08	0.10585E-08
0.33237E-07	0.10585E-08	0.10585E-08	0.33237E-07	0.10585E-08	0.10585E-08
0.33237E-07	0.10585E-08	0.10585E-08	0.33237E-07	0.10585E-08	0.10585E-08
0.33237E-07	0.10585E-08	0.10585E-08	0.33237E-07	0.10585E-08	0.10585E-08
0.33237E-07	0.10585E-08	0.10585E-08	0.33237E-07	0.10585E-08	0.10585E-08

COEFFICIENTS B, READ ROW WISE

-0.96676E-08	0.22511E-07	0.22511E-07	-0.96676E-08	0.22511E-07	0.22511E-07
-0.96676E-08	0.22511E-07	0.22511E-07	-0.96676E-08	0.22511E-07	0.22511E-07
-0.96676E-08	0.22511E-07	0.22511E-07	-0.96676E-08	0.22511E-07	0.22511E-07
-0.96676E-08	0.22511E-07	0.22511E-07	-0.96676E-08	0.22511E-07	0.22511E-07
-0.96676E-08	0.22511E-07	0.22511E-07	-0.96676E-08	0.22511E-07	0.22511E-07
-0.96676E-08	0.22511E-07	0.22511E-07	-0.96676E-08	0.22511E-07	0.22511E-07

COEFFICIENTS C, READ ROW WISE

-0.0	0.37156E-07	-0.37156E-07	-0.0	0.37156E-07	-0.37156E-07
-0.0	0.37156E-07	-0.37156E-07	-0.0	0.37156E-07	-0.37156E-07
-0.0	0.37156E-07	-0.37156E-07	-0.0	0.37156E-07	-0.37156E-07
-0.0	0.37156E-07	-0.37156E-07	-0.0	0.37156E-07	-0.37156E-07
-0.0	0.37156E-07	-0.37156E-07	-0.0	0.37156E-07	-0.37156E-07
-0.0	0.37156E-07	-0.37156E-07	-0.0	0.37156E-07	-0.37156E-07

EXPANSION WITH 11 FOURIER COEFFICIENTS

KS = 0 KS IS AN INDEX INDICATING TYPE OF SOLUTION: 0 FOR NORMAL, 1 FOR SINGULAR

FOURIER COEFFICIENTS

	CONSTANTS
TANG.	0.45455E 03
LONG.	0.28944E 01
SHEAR	0.56925E 00

	COS 1(THETA)	SIN 1(THETA)	COS 2(THETA)	SIN 2(THETA)	COS 3(THETA)	SIN 3(THETA)
TANG.	-0.57441E-03	0.32390E-04	0.56746E-04	-0.58088E-04	0.54121E-04	0.11337E-04
LONG.	-0.11386E 01	0.11385E 01	-0.43307E-04	-0.76463E-04	0.74386E-05	-0.55022E-04
SHEAR	0.53861E 01	-0.53860E 01	0.52491E-05	0.28910E-05	-0.14306E-05	-0.13928E-05

	COS 4(THETA)	SIN 4(THETA)	COS 5(THETA)	SIN 5(THETA)
TANG.	0.76199E-04	0.11885E-04	0.38986E-04	-0.78963E-05
LONG.	0.41156E-04	-0.55075E-04	-0.13349E-04	0.45193E-04
SHEAR	0.10598E-05	-0.10318E-05	0.22680E-06	-0.69870E-06

```
THETA =   0 DEGREES      POINT NO.   1
STRESSES        TANG.               LONG.                  SHEAR
ACTUAL       0.45455E C3       0.17552E 01          0.59553E 01
COMPUTED     0.45455E C3       0.17558E 01          0.59553E 01

THETA =  10 DEGREES      POINT NO.  11
STRESSES        TANG.               LONG.                  SHEAR
ACTUAL       0.45455E C3       0.19702E 01          0.49382E 01
COMPUTED     0.45455E C3       0.19707E 01          0.49382E 01

THETA =  20 DEGREES      POINT NO.  21
STRESSES        TANG.               LONG.                  SHEAR
ACTUAL       0.45455E C3       0.22133E 01          0.37884E 01
COMPUTED     0.45455E C3       0.22137E 01          0.37884E 01

THETA =  30 DEGREES      POINT NO.  31
STRESSES        TANG.               LONG.                  SHEAR
ACTUAL       0.45455E C3       0.24770E 01          0.25407E 01
COMPUTED     0.45455E C3       0.24774E 01          0.25407E 01

THETA =  40 DEGREES      POINT NO.  41
STRESSES        TANG.               LONG.                  SHEAR
ACTUAL       0.45455E C3       0.27534E 01          0.12331E 01
COMPUTED     0.45455E C3       0.27538E 01          0.12331E 01

THETA =  50 DEGREES      POINT NO.  51
STRESSES        TANG.               LONG.                  SHEAR
ACTUAL       0.45455E C3       0.30341E 01         -0.94609E-01
COMPUTED     0.45455E C3       0.30345E 01         -0.94604E-01

THETA =  60 DEGREES      POINT NO.  61
STRESSES        TANG.               LONG.                  SHEAR
ACTUAL       0.45455E C3       0.33104E 01         -0.14022E 01
COMPUTED     0.45455E C3       0.33110E 01         -0.14022E 01

THETA =  70 DEGREES      POINT NO.  71
STRESSES        TANG.               LONG.                  SHEAR
ACTUAL       0.45455E C3       0.35742E 01         -0.26498E 01
COMPUTED     0.45455E C3       0.35748E 01         -0.26498E 01

THETA =  80 DEGREES      POINT NO.  81
STRESSES        TANG.               LONG.                  SHEAR
ACTUAL       0.45455E C3       0.38172E 01         -0.37997E 01
COMPUTED     0.45455E 03       0.38180E 01         -0.37997E 01

THETA =  90 DEGREES      POINT NO.  91
STRESSES        TANG.               LONG.                  SHEAR
ACTUAL       0.45455E C3       0.40322E 01         -0.48168E 01
COMPUTED     0.45455E C3       0.40331E 01         -0.48168E 01

THETA = 100 DEGREES      POINT NO. 101
STRESSES        TANG.               LONG.                  SHEAR
ACTUAL       0.45455E C3       0.42126E 01         -0.56702E 01
COMPUTED     0.45455E C3       0.42135E 01         -0.56702E 01

THETA = 110 DEGREES      POINT NO. 111
STRESSES        TANG.               LONG.                  SHEAR
ACTUAL       0.45455E C3       0.43530E 01         -0.63341E 01
COMPUTED     0.45455E C3       0.43537E 01         -0.63341E 01
```

APPENDIX C

DIGITAL COMPUTER PROGRAM FOR SECTION 3 AND NUMERICAL RESULTS

Subroutine MACUTO presented in this Appendix provides a method for applying the theory developed in Section 3. Data for simulated situations can be obtained from subroutine CANTIL presented in Appendix A.

MACUTO has been programmed following closely the development of the method. Self explanatory comment statements are included, which detail the type of data to be used and the procedural sequence of the method. Print-outs present the data processed and the computed loading.

Use of the subroutines is made by a brief main program called TIBISAY. This program merely dimensions the subroutines, accepts and prepares the input data, and turns control over to subroutine MACUTO. The card arrangement of the source deck is similar to that shown in Fig. B.1.

Some sample results of the application made of the programs as specified in Section 3 are presented following the card listings of the programs.

```
//TIBISAY    JOB   '3324','TABORDA, JESUS A.',MSGLEVEL=1
//TAB  EXEC  FORTCLG
//FORT    EXEC  PGM=IEYFORT                                                    00000010
      DIMENSION AF1(3), AXM1(3), AF(3), AXM(3), F(3), XM(3), FWGHT(3),    CANTIL
     1 XL1(5), XL2(3), FR(3), FT(3), EZ(3), R(3), ALL1(3,360,5),          CANTIL
     2 SHTZT(3),SBZZ(3),SAZZ(3),SHFZR(3),SHFZT(3),SPRR(3),SPTT(3)         CANTIL
      DIMENSION  F(3,3)                                                   TRANSF
      DIMENSION   FORCE(3),XMOM(3),THETA(3),ST(3),SL(3),SH(3),Y(3,3)      MACUTO
      DIMENSION  A1(3),A2(3),A3(3),A4(3),F3(3),F4(3),F5(3),F6(3),        SCRATCH
     1 XM3(3),XM4(3),XM5(3),XM6(3),B1(3),B2(3),B3(3),B4(3),B5(3),B6(3)   SCRATCH
C
C
C   SPECIFY POISSON'S RATIO V, EXTERNAL AND INTERNAL PIPE DIAMETERS DO
C   AND DI, ANGULAR POSITION THETA OF THE POINTS, AND STRESS COMPONENTS:
C   TANGENTIAL ST, LONGITUDINAL SL AND SHEAR SH OF THE THREE POINTS 1,
C   2, AND 3 .
C
C     IF THE MATHEMATICAL MODEL OF A PIPE IS USED, OUTPUT ARGUMENTS OF
C     SUBROUTINE CANTIL, XNU AND ALL1 CAN BE USED FOR THIS.
C
      CALL        CANTIL(RO,RI,XE,G,XNU,SPECW,D,XL1,NPOINT,APEA,ALL1)
      V = XNU
      DO = RO + RO
      DI = RI + RI
      THETA(1) = 0.0
      THETA(2) = 120.0
      THETA(3) = 240.0
      ST(1) = ALL1(1,  1,1)
      ST(2) = ALL1(1,121,1)
      ST(3) = ALL1(1,241,1)
      SL(1) = ALL1(2,  1,1)
      SL(2) = ALL1(2,121,1)
      SL(3) = ALL1(2,241,1)
      SH(1) = ALL1(3,  1,1)
      SH(2) = ALL1(3,121,1)
      SH(3) = ALL1(3,241,1)
C
C
C   PREPARE STRESSES FOR IMPUT TO MACUTO.
C
C
      DO 1  I = 1, 3
      Y(1,I) = ST(I)
      Y(2,I) = SL(I)
    1 Y(3,I) = SH(I)
C
```

```
C
C     EVALUATE THE LOADING AT THE CROSS SECTION OF PIPE.
C
C
      CALL MACUTC(DO,DI,V,Y,THETA,P,FORCE,XMOM)
C
C
      END
```

```
      SUBROUTINE MACUTO(DO, DI, V, ALL, THETA, P, F, XM)
C
C
C  TO FIND THE LOADING ACTING THROUGH THE CROSS SECTION OF A PIPE FROM
C  THE STRESS COMPONENTS AT THREE POINTS OF THE EXTERNAL CIRCUMFERENCE
C  OF THE CROSS SECTION.
C
C
C     DO AND DI ARE EXTERNAL AND INTERNAL DIAMETERS OF THE PIPE RESPECTI-
C          VELY.
C     V IS POISSON'S RATIO.
C     ALL IS A 3X3 ARRAY CONTAINING THE STRESS COMPONENTS FOR THE THREE
C          POINTS.
C     THETA IS AN ARRAY CONTAINING THE ANGULAR POSITIONS OF THE POINTS.
C     P IS THE INFERRED INTERNAL PRESSURE OF THE PIPE.
C     F IS THE INFERRED FORCE.
C     M IS THE INFERRED MOMENT.
C
C
      DIMENSION  F(3), XM(3), ALL(3, 3), THETA(3)
      ABCF(A1,A2,A3,B1,B2,B3) = A1*B1+A2*B2+A3*B3
      WRITE(6, 500)
  500 FORMAT( 1H1, 7(/), 15X, 'INFERRED LOADING' // )
      RO = DO/2.0
      RO2 = DO*DO/4.0
      RI2 = DI*DI/4.0
      PI = 3.14159265
      AREA = PI*(RO2 - RI2)
      ERTIA = AREA*(RO2 + RI2)/4.0
      THETA2 = PI/180.0
      ENE = V + 1.5
      D = ((2.0*ENE - 2.0)*RO2 + 2.0*ENE*RI2)/(4.0*ERTIA*(1.0 + V))
C
C  IDENTIFY THE STRESS COMPONENTS , TANGENTIAL SPTT, LONGITUDINAL S
C  AND SHEAR T FOR POINTS 1, 2, AND 3 FROM ARRAY ALL.
C
C
      SPTT1 = ALL(1, 1)
         S1 = ALL(2, 1)
         T1 = ALL(3, 1)
      SPTT2 = ALL(1, 2)
         S2 = ALL(2, 2)
         T2 = ALL(3, 2)
      SPTT3 = ALL(1, 3)
         S3 = ALL(2, 3)
         T3 = ALL(3, 3)
C
C
```

```
C                                                                          MACUT049
C     CONVERT ANGULAR DEGREES TO RADIANS AND FIND DIFFERENCES BETWEEN      MACUT050
C     ANGLES.  FIND DIFFERENCES BETWEEN STRESS COMPONENTS.                 MACUT051
C                                                                          MACUT052
C                                                                          MACUT053
      Q1 = THETA(1)*THETA2                                                 MACUT054
      Q2 = THETA(2)*THETA2                                                 MACUT055
      Q3 = THETA(3)*THETA2                                                 MACUT056
      Q12 = (THETA(1) - THETA(2))*THETA2                                   MACUT057
      Q23 = (THETA(2) - THETA(3))*THETA2                                   MACUT058
      Q31 = (THETA(3) - THETA(1))*THETA2                                   MACUT059
      SINF1  = SIN ( Q1  )                                                 MACUT060
      SINF2  = SIN ( Q2  )                                                 MACUT061
      SINF3  = SIN ( Q3  )                                                 MACUT062
      SINF12 = SIN ( Q12 )                                                 MACUT063
      SINF23 = SIN ( Q23 )                                                 MACUT064
      SINF31 = SIN ( Q31 )                                                 MACUT065
      COSF1 = COS ( Q1 )                                                   MACUT066
      COSF2 = COS ( Q2 )                                                   MACUT067
      COSF3 = COS ( Q3 )                                                   MACUT068
      S32 = S3 - S2                                                        MACUT069
      S21 = S2 - S1                                                        MACUT070
      S13 = S1 - S3                                                        MACUT071
      T32 = T3 - T2                                                        MACUT072
      T21 = T2 - T 1                                                       MACUT073
      T13 = T1 - T3                                                        MACUT074
C                                                                          MACUT075
C                                                                          MACUT076
C     OBTAIN DENOMINATOR AND NUMERATOR OF THE FORCE AND MOMENT COMPONENTS. MACUT077
C     PERFORM THE CORRESPONDING DIVISIONS TO SOLVE FOR THE COMPONENTS.     MACUT078
C                                                                          MACUT079
C                                                                          MACUT080
      DENOM = ABCF( 1.0,1.0,1.0,SINF12,SINF23,SINF31 )                     MACUT081
      XMXNUM = ABCF(COSF1,COSF2,COSF3,S32,S13,S21 )                        MACUT082
       FXNUM = ABCF(COSF1,COSF2,COSF3,T32,T13,T21 )                        MACUT083
      XMYNUM = ABCF(SINF1,SINF2,SINF3,S32,S13,S21 )                        MACUT084
       FYNUM = ABCF(SINF1,SINF2,SINF3,T32,T13,T21 )                        MACUT085
      XMZNUM = ABCF(T1,T2,T3,SINF23,SINF31,SINF12 )                        MACUT086
       FZNUM = ABCF(S1,S2,S3,SINF23,SINF31,SINF12 )                        MACUT087
      XM(1) = XMXNUM/DENOM*ERTIA/RO                                        MACUT088
      XM(2) = XMYNUM/DENOM*ERTIA/RO                                        MACUT089
      XM(3) = XMZNUM/DENOM*ERTIA/RO*2.0                                    MACUT090
      F(1) = -FXNUM/DENOM/D                                                MACUT091
      F(2) = -FYNUM/DENOM/D                                                MACUT092
      F(3) =  FZNUM/DENOM*AREA                                             MACUT093
C                                                                          MACUT094
C                                                                          MACUT095
C     SOLVE FOR THE INTERNAL PRESSURE.                                     MACUT096
```

```
C                                                                               MACUT097
C                                                                               MACUT098
      P = ( SPTT1 + SPTT2 + SPTT3 )*( RO2/RI2 - 1.0 )/6.0                       MACUT099
C                                                                               MACUT100
C                                                                               MACUT101
C     PREPARE PRINT-CUTS OF THE INFORMATION PROCESSED AND THE INFERRED          MACUT102
C     LOADING.                                                                  MACUT103
C                                                                               MACUT104
C                                                                               MACUT105
      WRITE(6, 2)  THETA(1), (ALL(I,1), I = 1, 3 ),                             MACUT106
     1             THETA(2), (ALL(I,2), I = 1, 3 ),                             MACUT107
     2             THETA(3), (ALL(I,3), I = 1, 3)                               MACUT108
    2 FORMAT( //, 15X, 'STRESSES', 28X, 'TANG.', 17X, 'LONG.', 17X,             MACUT109
     1 'SHEAR' // (15X, 'THETA =', F7.2, ' DEGREES', 3E22.5 /) )                MACUT110
      WRITE(6, 3)  P, F, XM                                                     MACUT111
    3 FORMAT( // 15X, 'INFERRED PRESSURE',  E20.5, ' PSI' /                     MACUT112
     1           15X, 'INFERRED FORCE   ', 3E20.5, ' LBS' /                     MACUT113
     2           15X, 'INFERRED MOMENT  ', 3E20.5, ' LB-IN'  )                  MACUT114
C                                                                               MACUT115
C                                                                               MACUT116
      RETURN                                                                    MACUT117
      END                                                                       MACUT118
```

INFERRED LOADING

STRESSES	TANG.	LONG.	SHEAR
THETA = 0.0 DEGREES	0.45455E 03	-0.82505E 02	0.59553E 01
THETA = 120.00 DEGREES	0.45455E 03	0.16999E 02	-0.20473E 02
THETA = 240.00 DEGREES	0.45455E 03	0.74187E 02	0.16226E 02

INFERRED PRESSURE	0.10000E 03 PSI		
INFERRED FORCE	0.39339E 03	0.10000E 03	0.99999E 02 LBS
INFERRED MOMENT	-0.29000E 04	0.75009E 04	0.10000E 03 LB-IN

RADIAL DISTANCE OF POINTS = 6.00000 INCHES

LOADS APPLIED TO THE TIP

INTERNAL PRESSURE	=	100.00 PSI		
APPLIED FORCE	=	100.00	100.00	100.00 LB
APPLIED MOMENT	=	100.00	100.00	100.00 LB-IN

DISTANCE FROM THE TIP TO THE CROSS SECTION 30.00 INCHES

LOADS ACTING ON THE CROSS SECTION

INTERNAL PRESSURE	=	100.00 PSI		
APPLIED FORCE	=	393.39	100.00	100.00 LB
APPLIED MOMENT	=	-2900.00	7500.80	100.00 LB-IN

The stresses used as input for this inference were taken from this data which is similar to that shown in pg. . The inferred loading is in agreement with the actual one acting on the cross section.

APPENDIX D

Subroutine DSIMQ of the Computer Facility Center of the Naval Postgraduate School, to solve linear simultaneous equations.

```
C
C        SUBROUTINE DSIMQ                                              DSIMQ002
C
C  THIS WAS SLIGHTLY MODIFIED TO BE USED IN SINGLE PRECISION.
C                                                                      DSIMQ003
C        PURPOSE                                                       DSIMQ004
C           OBTAIN SOLUTION OF A SET OF SIMULTANEOUS LINEAR EQUATIONS, DSIMQ005
C           AX=B                                                       DSIMQ006
C                                                                      DSIMQ007
C        USAGE                                                         DSIMQ008
C           CALL DSIMQ(A,B,N,KS)                                       DSIMQ009
C                                                                      DSIMQ010
C        DESCRIPTION OF PARAMETERS                                     DSIMQ011
C           A AND B MUST BE REAL*8                                     DSIMQ012
C           A - MATRIX OF COEFFICIENTS STORED COLUMNWISE.  THESE ARE   DSIMQ013
C               DESTROYED IN THE COMPUTATION.  THE SIZE OF MATRIX A IS DSIMQ014
C               N BY N.                                                DSIMQ015
C           B - VECTOR OF ORIGINAL CONSTANTS (LENGTH N). THESE ARE     DSIMQ016
C               REPLACED BY FINAL SOLUTION VALUES, VECTOR X.           DSIMQ017
C           N - NUMBER OF EQUATIONS AND VARIABLES                      DSIMQ018
C           KS - OUTPUT DIGIT                                          DSIMQ019
C                0 FOR A NORMAL SOLUTION                               DSIMQ020
C                1 FOR A SINGULAR SET OF EQUATIONS                     DSIMQ021
C                                                                      DSIMQ022
C        REMARKS                                                       DSIMQ023
C           MATRIX A MUST BE GENERAL.                                  DSIMQ024
C           IF MATRIX IS SINGULAR , SOLUTION VALUES ARE MEANINGLESS.   DSIMQ025
C           AN ALTERNATIVE SOLUTION MAY BE OBTAINED BY USING MATRIX    DSIMQ026
C           INVERSION (MINV) AND MATRIX PRODUCT (GMPRD).               DSIMQ027
C                                                                      DSIMQ028
C        SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED ... NONE        DSIMQ029
C        METHOD                                                        DSIMQ032
C           METHOD OF SOLUTION IS BY ELIMINATION USING LARGEST PIVOTAL DSIMQ033
C           DIVISOR. EACH STAGE OF ELIMINATION CONSISTS OF INTERCHANGINGDSIMQ034
C           ROWS WHEN NECESSARY TO AVOID DIVISION BY ZERO OR SMALL     DSIMQ035
C           ELEMENTS.                                                  DSIMQ036
C           THE FORWARD SOLUTION TO OBTAIN VARIABLE N IS DONE IN       DSIMQ037
C           N STAGES. THE BACK SOLUTION FOR THE OTHER VARIABLES IS     DSIMQ038
C           CALCULATED BY SUCCESSIVE SUBSTITUTIONS. FINAL SOLUTION     DSIMQ039
C           VALUES ARE DEVELOPED IN VECTOR B, WITH VARIABLE 1 IN B(1), DSIMQ040
C           VARIABLE 2 IN B(2),........, VARIABLE N IN B(N).           DSIMQ041
C           IF NO PIVOT CAN BE FOUND EXCEEDING A TOLERANCE OF 0.0,     DSIMQ042
C           THE MATRIX IS CONSIDERED SINGULAR AND KS IS SET TO 1. THIS DSIMQ043
C           TOLERANCE CAN BE MODIFIED BY REPLACING THE FIRST STATEMENT. DSIMQ044
C
C
C
C
```

```
C
      SUBROUTINE DSIMQ(A,B,N,KS)                                        DSIMQ048
C     REAL*8 A,B,BIGA,TOL,SAVE,DABS                                     DSIMQ049
      DIMENSION A(1),B(1)                                               DSIMQ050
C                                                                       DSIMQ051
C        FORWARD SOLUTION                                               DSIMQ052
C                                                                       DSIMQ053
C     TOL=0.0D0                                                         DSIMQ054
      TOL=0.0                                                           DSIMQ054
      KS=0                                                              DSIMQ055
      JJ=-N                                                             DSIMQ056
      DO 65 J=1,N                                                       DSIMQ057
      JY=J+1                                                            DSIMQ058
      JJ=JJ+N+1                                                         DSIMQ059
C     BIGA=0.0D0                                                        DSIMQ060
      BIGA=0.0                                                          DSIMQ060
      IT=JJ-J                                                           DSIMQ061
      DO 30 I=J,N                                                       DSIMQ062
C                                                                       DSIMQ063
C        SEARCH FOR MAXIMUM COEFFICIENT IN COLUMN                       DSIMQ064
C                                                                       DSIMQ065
      IJ=IT+I                                                           DSIMQ066
C     IF (DABS(BIGA)-DABS(A(IJ))) 20,30,30                              DSIMQ067
      IF ( ABS(BIGA)- ABS(A(IJ))) 20,30,30                              DSIMQ067
   20 BIGA=A(IJ)                                                        DSIMQ068
      IMAX=I                                                            DSIMQ069
   30 CONTINUE                                                          DSIMQ070
C                                                                       DSIMQ071
C        TEST FOR PIVOT LESS THAN TOLERANCE (SINGULAR MATRIX)           DSIMQ072
C                                                                       DSIMQ073
C     IF (DABS(BIGA)-TOL)  35,35,40                                     DSIMQ074
      IF ( ABS(BIGA)-TOL)  35,35,40                                     DSIMQ074
   35 KS=1                                                              DSIMQ075
      RETURN                                                            DSIMQ076
C                                                                       DSIMQ077
C        INTERCHANGE ROWS IF NECESSARY                                  DSIMQ078
C                                                                       DSIMQ079
   40 I1=J+N*(J-2)                                                      DSIMQ080
      IT=IMAX-J                                                         DSIMQ081
      DO 50 K=J,N                                                       DSIMQ082
      I1=I1+N                                                           DSIMQ083
      I2=I1+IT                                                          DSIMQ084
      SAVE=A(I1)                                                        DSIMQ085
      A(I1)=A(I2)                                                       DSIMQ086
```

```
C
C
C
C        DIVIDE EQUATION BY LEADING COEFFICIENT                                 DSIMQ088
C                                                                               DSIMQ089
   50 A(I1)=A(I1)/BIGA                                                          DSIMQ090
      SAVE=B(IMAX)                                                              DSIMQ091
      B(IMAX)=B(J)                                                              DSIMQ092
      B(J)=SAVE/BIGA                                                            DSIMQ093
C                                                                               DSIMQ094
C        ELIMINATE NEXT VARIABLE                                                DSIMQ095
C                                                                               DSIMQ096
      IF(J-N) 55,70,55                                                          DSIMQ097
   55 IQS=N*(J-1)                                                               DSIMQ098
      DO 65 IX=JY,N                                                             DSIMQ099
      IXJ=IQS+IX                                                                DSIMQ100
      IT=J-IX                                                                   DSIMQ101
      DO 60 JX=JY,N                                                             DSIMQ102
      IXJX=N*(JX-1)+IX                                                          DSIMQ103
      JJX=IXJX+IT                                                               DSIMQ104
   60 A(IXJX)=A(IXJX)-(A(IXJ)*A(JJX))                                           DSIMQ105
   65 B(IX)=B(IX)-(B(J)*A(IXJ))                                                 DSIMQ106
C                                                                               DSIMQ107
C        BACK SOLUTION                                                          DSIMQ108
C                                                                               DSIMQ109
   70 NY=N-1                                                                    DSIMQ110
      IT=N*N                                                                    DSIMQ111
      DO 80 J=1,NY                                                              DSIMQ112
      IA=IT-J                                                                   DSIMQ113
      IB=N-J                                                                    DSIMQ114
      IC=N                                                                      DSIMQ115
      DO 80 K=1,J                                                               DSIMQ116
      B(IB)=B(IB)-A(IA)*B(IC)                                                   DSIMQ117
      IA=IA-N                                                                   DSIMQ118
   80 IC=IC-1                                                                   DSIMQ119
      RETURN                                                                    DSIMQ120
      END                                                                       DSIMQ121
                                                                                DSIMQ122
```

APPENDIX E

Effects of Changing the Number of Fourier Coefficients and the Amount and Quality of the Data in the Application of the Theory Developed in Section 2.

The theory developed in Section 2 of this thesis estimates Fourier coefficients of the distributions of axial, tangential, and shear stresses assuming that enough data has been obtained by placing a sufficient number of strain gage elements around the external surface of a cross section of pipe. The correctness of the estimated coefficients depends on their number and on the amount and quality of the data. Depending on the relative orientation of the gage elements, they can pick information useful for determining the coefficients of all the distributions, or, if they are arranged in certain disadvantageous ways, they may be able to provide information for none, or only some of the coefficients.

The requirement of inferring a given number N of Fourier coefficients, demands having, at a minimum, a corresponding number $M = M(N)$ of valid data items. If more data are available, there is a redundance of data which permits more accurate determination of the N coefficients.

Specific rules for the necessary number and disposition of gage elements to obtain a specified number of correct coefficients are not available, but they probably could be worked out. Some idea of the gage elements requirements can be obtained by testing actual cases and comparing results with correct ones obtained from other methods. The digital computer programs included in this thesis can be used as they are to perform such tests. The procedure to follow is to simply specify in subroutine ZULIA the number of gage elements, their angular positions and angular orientations around the cross section, and the number of Fourier coefficients to be computed. The print-out of this program presents the

distributions obtained in this way, shown adjacent to the theoretically correct ones, so that comparisons can be readily done.

A preliminary survey of gage elements arrangements was made using that procedure, applied to data with no added random errors. Results obtained are presented following these pages. Many of these results might have been anticipated from theoretical considerations. The following nomenclature is used when applicable:

(a) No. of coefficients

3 to 11: the results presented were obtained using from three to eleven Fourier coefficients per series. These results apply to that number of coefficients.

7: results apply only to seven coefficients.

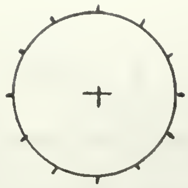
(b) Results

good: indicates that the coefficients obtained describe correctly the tangential, axial and shear stress distributions.

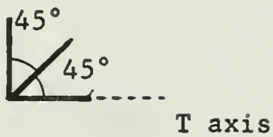
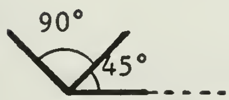
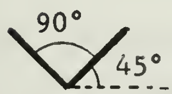
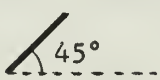
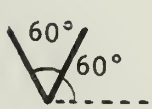
bad: The computed coefficients do not describe either of the distributions.

only shear good: good coefficients were obtained only for the shear stress distribution.

Inasmuch as the data were without added errors, the recovery should be and actually was excellent or no good at all; accordingly, there is nothing subjective in the judgment "good" or "bad".

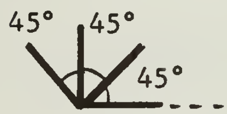
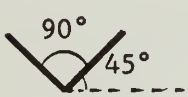
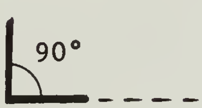


Gage elements located at 12 points equally spaced 30° around the external circumference of the cross section.

gage elements arrangement at each point	No. of Fourier coefficients per series	results
	3 to 11	good
	3 to 11	good
	3 to 11	only shear good
	3 to 11	bad
	3 to 11	bad
	3 to 11	good
	3 to 11	only shear good
	3 to 11	bad

II)

Gage elements located at 8 points equally spaced 45° around the external circumference of the cross section.

gage elements arrangement at each point	No. of Fourier coefficients per series	results
	3 to 7	good
same	9 and 11	bad
	3 to 7	good
same	9 and 11	bad
	3 to 7	only shear good
same	9 and 11	bad
	3 to 11	bad
	3 to 11	bad

III)

One gage element every 10° around the external circumference of the cross section, totaling 36 elements. The first element at 0° from the tangential direction, and every consecutive one, incrementing this angle by 10°.

from 3 to 11 coefficients: bad results

IV)

One gage element every 10° around the external circumference of the cross section, totaling 36 elements. The first element at 0° from the tangential direction, and every consecutive one, incrementing this angle by 50°.

from 3 to 9 coefficients: good results

11 coefficients: bad results

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13. ABSTRACT

This thesis presents a method for estimating the distribution of stress components around the outer circumference of a cross section of a pipe, from the readings of strain gage elements arbitrarily positioned and oriented around this circumference. A least-squares procedure is used to obtain best estimates of the coefficients of Fourier expansions describing such distributions. A digital computer program was developed for applying the method. Data for testing the method and program were generated by a computer program using the best available theory of stress analysis in pipes. Methods for adding random errors to the data were adapted and used for closer simulation of actual situations.

A second problem treated in this thesis is that of inferring the loading acting through the cross section of a straight pipe of concentric bore from known stresses at points on the external surface of the cross section which is presumed to be distant from stress condentrations. It is shown that this inference can be made from stresses at only three points of the cross section. A digital computer program was developed to do this.

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